COMSTOCK

Various Aspects of the Steel Rail Question

Civil Engineering

C. E.

1913

VARIOUS ASPECTS OF THE STEEL RAIL QUESTION

BY

ARTHUR FRANCIS COMSTOCK

B. S. University of Illinois

1906

THESIS

Submitted in Partial Fulfillment

of the Requirements for the

Degree of

CIVIL ENGINEER

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1913

UNIVERSITY OF ILLINOIS

THE GRADUATE SCHOOL.

April 8, 1913.

I hereby recommend that the thesis prepared by A. F. COMSTOCK, B. S., entitled VARIOUS ASPECTS OF THE STEEL RAIL QUESTION, be accepted as fulfilling this part of the requirements for the degree of Civil Engineer.

Ira O. Baker.

Head of Department
in Charge of Major Work.

Recommendation concurred in:

A. N. Talbot

H. H. Stock

Committee on Final Examination.

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VARIOUS ASPECTS OF THE STEEL RAIL QUESTION.

Introduction.

Perhaps there is no more puzzling problem confronting railway engineers today than the problem of rail failures. Engineers of the highest attainments and repute have devoted their lives to the study of the proper design and manufacture of the steel rail; committees of our foremost technical societies have investigated and reported upon the problem; metallurgists have considered the subject in minute detail; yet, despite all this pain-taking care and intense scientific research extending over the last forty years, the present-day rails are not giving satisfactory service. Many of the points which have been long in dispute are still matters of contention. Unfortunately some of the most promising theories have not been borne out by long experience. The result of all this uncertainty is that tremendous efforts are now being put forth to remedy the evil. The writer advances the hypothesis that we have either overlooked some essential fact or law, or discarded some seemingly trivial point which exercises a vital influence upon the rail. What this particular point may be is the subject of this discussion. In attempting to find the missing link a good many aspects of the question will need to be considered, touching the various transitions in the life of the rail; beginning with its manufacture and ending with its service in the track. The history of steel rail development will be taken up first, after which the various aspects of the subject will be presented.

HISTORY OF STEEL RAIL DEVELOPMENT.

The discovery of the Bessemer Process of steel manufacture in 1855 and its commercial development in America as applied to rails, beginning in 1867, have been of tremendous moment in American civilization. Previous to this time the railroads had to rely solely upon the old wrought iron rails, which finally grew incapable of supporting the heavier wheel-loads or of withstanding the abrasion and wear caused by the increasing number of trains in the late '60's. The fibrous structure of the iron rail was easily broken down. Crushing of the head due to laminations in the metal became so common, as the wheel loads were increased, that the life of iron rails was reduced in many cases to only a few months. The constant effort and expenditure required to keep the track in safe and passable condition became almost prohibitive during the last year of iron rails, and paved the way for the rapid adoption of steel.

Many writers, however, have mistaken the early reception of the steel rail as an unqualified endorsement, and an expression of complete satisfaction on the part of the railways with Bessemer steel. Such, however, was not the case. We must remember, as above stated, that the failure of the iron rail had created a firm demand and even a necessity for better rails. The railways were eager to replace the iron rails with something better. The steel rail was adopted because it was a better rail than the iron rail, not because it was perfect. Naturally it took some time after the first steel rails were put into use to measure and study their performance.

Wellington, while admitting in 1887 that steel rails had revolutionized track maintenance, complained that far too many steel rails of inferior quality had been laid.

As the heavier locomotive wheel-loads of 1865-1875 had proved the undoing of the iron rail, so the large percentage of increase in the loads per wheel during and since the decade beginning in 1890, together with other developments in the manufacture and duty of the rail, have produced a large number of failures in steel rails, and have caused an increasing agitation on the part of the railways and the public for better rails. This agitation has grown in force and has continued down to the present day.

The Bessemer rail was used exclusively upon American railways until 1900, when open-hearth steel rails were experimented with. Open-hearth steel had been specified for some years in the manufacture of structural steel, and, on account of the greater uniformity which was claimed for it, and the general dissatisfaction with Bessemer rails at that time, considerable impetus was given the movement for open-hearth rails. The manufacturers, however, were loath to discard their expensive Bessemer plants, and for this reason they opposed the general adoption of open-hearth steel for rails. Not until statistics were available which showed conclusively that open-hearth steel rails were more reliable than Bessemer, resulting in a firm and continued demand on the part of the railways for open-hearth steel, did the manufacturers seriously consider changing to the former process. In the six years ending Oct. 31, 1911, the proportion of open-hearth rails in use on American railways had rapidly increased until it reached, at that time, 11% of the total rail in use, while during the year 1910 open-hearth steel

constituted 45% of the total rail-steel manufactured in the United States. This proportion is increasing even more rapidly at the present time, and as most of the manufacturers are already replacing their Bessemer plants with open-hearth furnaces, or converting them into some form of duplex process, the day of a great predominance of open-hearth rails cannot be but a few years hence. The comparative amounts of open-hearth and Bessemer steel rails produced from 1900 to 1911 are shown in Table 5. page 66.

FAILURE OF RAILS TO MEET MODERN REQUIREMENTS.

As the Bessemer rail eliminated only a part of the rail difficulties inherent in the iron rail, so the open-hearth rail, at its best, has only lessened the evils of the Bessemer rail. There have been those who have urged the adoption of the open-hearth rail as a panacea for all rail-ills; but this view must be regarded as an erroneous one until future improvements in manufacture shall permit us to make better rails than we have hitherto done. It is true that the number of rail-failures per mile of track has been reduced almost one-half by open-hearth steel; but it is equally true that the performance of open-hearth rails is now based upon small lots or tonnages of comparatively new rails. This should make us cautious in our claims for their superiority. It is also pertinent to say that some of the most disastrous wrecks due to broken rails have occurred with open-hearth rails, notably the Manchester wreck on the Lehigh Valley Railroad in August, 1911. Abundant proof will be given in a subsequent paragraph to the effect that open-hearth

rails have not yet proved as free from defects as we should like to see them. The large amount of attention which the subject of rail-failures is receiving at the present time is proof that there is much apprehension existing in the minds of the rail-users regarding the quality of service which steel rails are now giving. As a further evidence of the unsatisfactory performance of present-day rails, it may be said that only a few months ago the National Association of Railroad Commissioners at their annual convention in Washington, D. C., considered the question of placing the entire matter of rail inspection in the hands of the Government. While this course was not finally recommended, it was very seriously considered.

In all fairness, therefore, it cannot be said that either the iron rail or the steel rail has ever given complete satisfaction on American railways. This is a very important point and must be kept continually in mind. Certain cases appear where a special type of rail or a special lot of rails from a given manufacturer gave excellent results, usually under some special conditions of service; but these have been the exceptions. Statistics are not available to show the percentage of failures during the several periods of rail development. It is very much to be regretted that this is so. Nevertheless, the writings of the engineers of the early days of steel-rail manufacture show conclusively that the steel rail has never been entirely free from defects, even under the lighter wheel-loads of a generation or more ago. As for the iron rails, we know that they were wholly unfit for the task of supporting half the wheel-loads of the present day, and the time was welcomed by the railways that marked the supplanting of the iron rail by Bessemer steel. In the same way the railways are now demanding the sub-

stitution of open-hearth steel for Bessemer steel in the manufacture of rails. Experience has proved that open-hearth rails are more reliable than Bessemer, and are better suited to modern conditions of traffic; but we must remember that the performance of the open-hearth rail is not yet satisfactory, it is merely "better than the Bessemer rail".

Reference has already been made to the various aspects which present themselves in the consideration of the cause of rail-failures. In the first place the responsibility for the performance of rails must rest with either the rail manufacturer or the rail consumer, or perhaps more truly, with both. In the past, each party has attempted to find the cause for rail failures by picking flaws in the methods and processes used by the other, and since neither understood the other parties' business nearly so well as he understood his own, not much real light was thrown upon either side of the question. Even at the present time the American Railway Engineering Association is spending thousands of dollars investigating every possible aspect of the manufacture of rails, and some things of decided importance are being accomplished; but practically nothing is being done by the railways to determine the exact effects of different conditions of track and track maintenance, except the investigations of Dr. P. H. Dudley. While the statistics of rail-failures which the American Railway Engineering Association has been collecting for the last few years are interesting as a basis of comparison of the different types and weights of rail, and for other pertinent comparisons, they offer but incomplete data regarding the actual cause of rail-failures. This will be

more fully discussed later.

VARIOUS ASPECTS OF SUBJECT.

The two main aspects of the rail question, then, are from the side of the manufacturer and the side of the consumer. The manufacturer is blamed if the rails break, regardless of the fact that the specifications may have been strictly adhered to, and notwithstanding the fact, also, that the consumer has designed and specified the section of the rail. The manufacturer's troubles begin with the ore. Two-thirds of all the ore now used for making rail-steel is Messabi ore from the northern ranges. While the difficulty of producing low-phosphorous steel from high-phosphorous ore is not so potent with the basic open-hearth process as with the acid Bessemer process, it is still to be contended with, since practically all of the ore now in sight is high in phosphorous. The questions of the size of heat, method of pouring and recarburizing, size and shape of ingot, segregation and pipe in ingot, percentage of discard, speed and temperature of rolling, and care in straightening and handling the rail, are all important aspects of the subject which the manufacturer must be concerned with. The consumer, or railway, likewise has several important aspects to deal with. The design of the rail-section, weight of rail, the specifications and inspection of manufacture, the service or duty the rail is subjected to, the maintenance of the track and foundation of the rail, are all in the hands of the consumer. These various aspects make the problem of securing satisfactory rails for modern conditions of railway traffic indeed a difficult one, and a problem of vast importance to both

parties, as well as to the travelling public. While it is disappointing to observe the lack of frankness and co-operation between the manufacturer and the consumer in the past, the future promises to ring in a new era which shall be characterized by an eagerness on the part of each to assist the other in the true solution of the difficulties involved. This feeling is already becoming a reality and has borne some fruit.

RAIL SECTIONS.

Principles of Design.

One of the most discussed questions concerning rail betterment has been the question of proportions of metal in the rail, i.e. rail-sections. The manufacturers and consumers have locked horns repeatedly over rail-sections. Before tracing the development of the standard sections and comparing their properties, let us consider the principles underlying their design. It has been often said that no mathematical treatise of the stresses in the rail is possible; but since almost all of the indeterminate factors must operate to increase rather than to decrease the known stresses, we can at least arrive at a fair minimum value and perhaps this may be made a reasonable basis for further argument.

Under the most favorable circumstances of perfect track and wheels, a rail may be represented as a continuous beam on flexible supports spaced 20 inches center to center. A static wheel-load of 30,000 lbs. will produce a tensile stress of 7,000 lbs. per sq. in. in the base of 100-lb. rail, under the foregoing conditions. If

the span were taken as a simple beam instead of a continuous beam the stress would be increased to 10,000 lbs. But we will use the smaller value as it probably more nearly represents actual conditions and it will be on the safe side. A 100-lb. rail has been selected because it is our heaviest standard rail. The wheel-load of 30,000 lbs. is not the greatest in use with 100-lb. rail, but it is believed by the writer to be typical of present practice on the roads which operate the fastest trains over 100-lb. rail.

In addition to the static stress, we have several phases of shock resulting from the speed of the train. Several of these are indeterminate, although two of the most important may be arrived at with a fair degree of accuracy. It is an established principle of mechanics that a load suddenly applied will produce as much as twice the stress in a member that will be caused by the same load at rest. The stress due to impact of the wheel-load is, then, 7,000 pounds, making a total stress due to the two forces of 14,000 pounds per square inch. It is hardly possible to say at just what speed the load should be considered as suddenly applied; but since speeds of 80 miles per hour are not uncommon with passenger trains (corresponding to a speed of 117 ft. per second), there appears to be no grounds for disputing that the load is, indeed, very suddenly applied. The certainty that the load must be suddenly applied is further increased by the great variations in speeds of different trains over any given main-line track, for the speeds will surely vary from 0 to 60 or 80 miles per hour in almost any case. This would destroy any argument that the load was so suddenly applied as not to be fully felt.

Another serious augment to the rail-stress is the pounding effect of the counter-weight of the locomotive driving-wheel. Mr. D. L. Barnes has shown, in vol. 16 of the Transactions of the American Society of Mechanical Engineers, that the pressure of the wheel on the rail may be doubled by the unbalanced effect of the counter-weight when the wheel revolves at high speed. This fact is not only generally admitted, but many cases are on record where the permanent set left at regular intervals in 75-pound rails by a locomotive passing over the track at excessive speed, has made it necessary to remove hundreds of rails from the track. Moreover, it has been shown by Dr. W. F. M. Goss in his noted experiments upon the locomotive "Schenectady" at the Purdue Laboratory, and recorded in the Transactions of the American Society of Mechanical Engineers, vol. 16, that the contact of the revolving driving-wheel with the rail is not continuous, even when the pressure is greatest, but is a rapid succession of impacts, and that the driving-wheels tend to leave the track due to the upward inertia of the counter-balance, whenever the maximum speed is exceeded for which the counter-balance was designed. It is thus apparent that a wheel-load of 30,000 pounds might be and no doubt would be augmented 100 per cent due to the counter-balance, and this would add another 7,000 pounds to the stress at certain points in the rail, making in all a tensile stress in the base of the rail of 21,000 lbs. per sq. in.

That 21,000 pounds is a conservative estimate of the unit-stress in a 100-pound rail under the foregoing conditions, is better understood when it is realized that no consideration has been given to several elements which operate to increase rather than to decrease the value obtained. The impractibility of having consecutive bear-

ings on the ties in horizontal or even parallel planes, frequently introduces a torsional stress in the rail in combination with tension or compression. The impractibility of maintaining track on a perfectly uniform level or grade and the difficulty of keeping both rails at the same elevation over any given tie, certainly increases the shock of the wheel on the rail in amount proportional to the roughness of the track. This is especially true during the winter when the ballast freezes, reducing the cushioning effect under the tie, and preventing the track from being properly adjusted. Heaving of the frozen ballast further adds to the roughness of track. The manner in which this increased stress is manifested may be due to a pounding or hammer-blow of the wheel as it strikes a high spot or drops into a low spot or strikes a worn spot resulting from slipping of the drivers, or it may be due to a side-thrust of the wheel caused by rocking of the locomotive, or quite likely to both. The question of defective wheels need not be cited in this connection, for they are not of regular occurence, although when present they may do a great damage. The side-thrust of the locomotive due to taking steam on one side while the other side is on dead center is another source of eccentric stress difficult to analyze, but nevertheless of some moment.

Experiments are not lacking to show that 21,000 pounds per square inch is a conservative estimate of the actual stress in a 100-pound rail under a 30,000 pound wheel-load at high speed. Dr. P. H. Dudley, consulting engineer of the New York Central Lines, has made, during the last fifteen years, many measurements of the unit-firer stresses in rails under ordinary conditions of traffic.

Dr. Dudley invented for this purpose a stremmatograph, which is a small instrument that can be clamped to the base of the rail, so that it automatically measures and records the deformation produced by tension or compression in the base of the rail over a length of five inches. Knowing the properties of the rail section and the modulus of elasticity of the steel, the unit-fiber stress is computed. In an article contained in Bulletin No. 151 of the American Railway Engineering Association, Dr. Dudley reports the results of stremmatograph tests upon 6-inch, 100-pound rail of the Dudley section, with an Atlantic type passenger engine having 26,000 pounds on each of two driving-wheels on each side, spaced seven feet center to center. The speed during the observations was five miles per hour, and the tie-spacing twenty inches. It will be evident that the wheel-load is less in this instance than that assumed above, and yet Dr. Dudley found a unit-stress of 19,800 pounds under the front driver and 10,000 pounds under the other, while the stress under the training wheel (with a wheel-load of only 17,000 pounds) was found to be almost 12,000 pounds per square inch. At a speed of sixteen miles per hour with the same locomotive, on the same day, the stress under the front driver increased to 22,000 pounds. Other tests made upon lighter rail and at greater speeds confirm the reliability of these results, and show but a trifling, if any, factor of safety in many cases. The writer concludes, therefore, that the maximum fiber-stress due to tension in the base of a 100-pound rail under modern passenger traffic conditions is not less than 21,000 pounds per square inch.

Reversal of Stresses in Rail.

Unfortunately the rail must endure greater duty than that due to repeated tension or repeated compression. As soon as any point of the rail is between two wheels or in front or just back of the front or rear wheel, the stress is reversed, i.e., the base is in compression and the head in tension. Dr. Dudley found that the maximum compression in the base amounted to about ten to twenty-five per cent of the maximum tensile stress. Since the passing of every wheel must produce alternate tension and compression, every infinitesimal section along the rail and every point in every section, excluding those which lie in the neutral axis, must suffer not only repeated stress but reversal of stress as well. Surely this is a great burden to add to a structure already suffering from a ponderous duty.

Wear of Rail.

Another difficult function which the rail must perform is that of resisting wear. On tangent or straight track the wear is principally confined to the top or tread of the rail, while on the outside rail of curved track the side of the head is often worn rapidly away, producing an unsymmetrical head. Ordinarily the life of a rail on straight track is determined by the resistance of the metal in the head to crushing, although the wear is indeed appreciable. The factor of safety certainly should be sufficient to guard against weakness due to wearing of the rail and its consequent reduction in area.

Initial Compressive Stress under Wheel.

Direct compression in the rail at the points of contact with the wheel is also a serious stress. Impact due to speed, and the hammer-blow effects of rough track, low-joints and imperfect wheels, unite to make conditions unusually severe. Professor J. B. Johnson found by experimenting upon wheels of different diameters and loads that the area of contact between wheel and rail is approximately circular and about equal to one square inch. The maximum compressive stress was found to be 164,000 pounds per square inch and the mean intensity of stress 82,000 pounds per square inch. While it is extremely difficult to determine any precise values in this way, it is clear that if the dynamic augment of the wheel-load is 200 per cent, and we have good reason to believe that it is, we may expect the compression directly beneath the wheel to be at least 90,000 pounds, considering a wheel-load of 30,000 pounds, at high speed and on the best track.

Cantilever Action of Rail-Base.

The rail-base, through eccentric loading or side pressure from the wheel-flanges oftentimes is made to act as a cantilever beam. This will be more clearly understood by referring to Fig. 6, page 74, which shows a full-size section of a standard wheel resting upon a 100-lb. rail. It will be observed that conditions therein represented are typical of a new wheel and a new rail. Under these circumstances the center of pressure normally will be more than one-quarter of an inch inside of the center line of rail, while under the worst

conditions it may be at times as much as one-half inch inside or one-half inch outside the center-line of rail. Such eccentric loading produces a cantilever action in one half of the base difficult to treat mathematically, but none the less severe. The same reactions are caused by side pressure transmitted to the rail from the wheel-flanges, either on curves or tangent track. Many of the base-failures over ties can be traced to this cause. With old rails and wheels the normal center line of pressure is central with respect to the rail, but the lateral side motion of the wheels is increased by reason of the excessive wear, thus making the rail more subject to enhanced strains from side pressure.

Low Ties and Their Effect upon Stresses in Rail.

It often happens that because of insufficient tamping, or settling of the ballast or subgrade at a certain point or points, a tie will settle to a lower elevation than those adjoining. The natural result of this deficiency is to lengthen the span of beam (the rail), so that its may even become as much as twice its normal length, thereby causing twice the normal stress in the rail that we have already computed. Such a condition would not be likely to continue for any great length of time in track well maintained, but anyone who has had occasion to inspect much track will realize that this defect is more than a possibility.

Temperature Stresses.

The temperature stresses in rail are not to be neglected by any means, even though they are indeterminate in amount. The maximum temperature stress may exist in the rail on the coldest

winters' night just at the instant that the fastest passenger train rushes by. Furthermore, a combination of any or all the aforesaid defects of rail, track and rolling-stock may be present with the temperature stress and conspire to make certain a broken rail.

The colder temperatures also impart brittleness to the steel, which is especially noticeable on those roads subject to extremely low temperatures. In New York state for instance, the records of the Public Service Commission show that there are from three to eight times as many failures per month during the months of January, February and March as there are during the other nine months. How many of these failures are due to temperature stresses in combination with the others, and how many are due to brittleness, is not clear; but the cold weather is a menace in either case. In the preceding paragraphs have been discussed the variety and intensity of stresses which our heaviest rails are subjected to. We may conclude that under the most favorable conditions, which usually occur only in short stretches of track, the stresses are, under the fast trains, at least 21,000 lbs. per sq. in., and under ordinary conditions may be very much in excess of this amount. The elastic limit of rail steel ranges from 50,000 to 60,000 lbs. and the ultimate strength from 100,000 to 120,000 lbs. per sq. in. While 21,000 lbs. might be considered a safe working unit-stress under the very best conditions, it certainly is not conservative in view of the several uncertainties which characterize modern rail-duty. There are few structures indeed, which suffer the severity and variety of stresses as do modern rails. Conservatism certainly has not guided us in rail design. A sufficient factor of safety to guard against the

physical and mechanical defects of the steel and the uncertain eccentricities of loading, in addition to the usual stresses, has not been allowed. This must be due to one of three things. Either the wheel-loads or the speeds have been permitted to increase faster than the required weight of rail, or else the rail has always been deficient in strength and the new designs have merely repeated past mistakes. The ease and facility with which broken rails may be detected and replaced, and the infinitesimally small percentage of failed rails which have caused derailments must both tend to lessen conservatism in design. Another detriment to proper rail design has been the natural tendency of the railways to blame the quality of metal for all rail failures. This tendency is widely dominant today. Since many of the failures reveal faulty manufacture, the common conclusion seems to be that this is the only fault to be remidied. We should, of course, improve the quality and uniformity of the steel just as much as possible; but we should remember, at the same time, that because a chain breaks at its weakest link, is not proof that the chain would not have broken at the same spot had the link been as strong as the rest. The factor of safety in rail design should be made high enough to compensate for such of the physical defects of the steel as are inherent in the manufacture.

Now that we have discussed the abnormal duty and stresses that the heaviest and strongest standard rail is subjected to under modern traffic conditions, it is pertinent to inquire into the evolution of our standard "T"-rail, and find out, if possible, on what theory it has been developed.

Development of Principal Sections.

The "T"-rail is an American invention, having been invented by Col. Robert L. Stevens, chief engineer of the Camden & Amboy Railway in 1830. Previous to that time the track consisted of wrought-iron straps or bars about 2 1/2" wide and 3/8" thick fastened on top of a timber stringer (usually 6" x 6"), and the stringer in turn was supported on timber or stone sleepers. The locomotives at that time weighed only about eight tons, while the speed usually did not exceed 15 miles per hour. Col. Stevens' rail was the prototype of our present "T"-section, forming as it did the bearing surface for the wheel and the guide for the wheel flanges, and having also the necessary strength as a girder as well as a flat base for bearing on the tie. This form of rail did not come into general use, however, for several years owing to the fact that it was expensive to manufacture, all rails being at first imported from England. The head of this rail was somewhat pear-shaped, the radius of its tread being about 6".

By 1850 iron plants had begun to operate in the United States, and iron "T"-rails were supplied in quantities sufficient to meet the demands of increased mileage. They were generally about 3 1/2" high and weighed about 50 lbs. per yd. As soon as the wheel-loads were increased to about 10,000 pounds, and the express train speeds were increased to 30 miles per hour, iron rails proved unequal to the duty thus imposed upon them, and Bessemer steel rails were imported from England as early as 1863, even at a cost of $250

per ton, or twice as much as iron rails. Bessemer steel plants were constructed in America in 1865, and at first the rails were rolled in the same rolls that had been used for the old iron rails. One of the first and most widely used sections designed for Bessemer rail, is shown in Fig. 8, page 76, the Ashbel Welch section, designed by Mr. Ashbel Welch in 1866 for the Camden & Amboy Railroad. This rail weighed 57-1/2 lbs. per yd. and its height and width of base were each 4". It was a modification of the old iron pear-head sections, and conformed somewhat closely in the distribution of metal to our present-day standards.

In 1870 the New York Central Railroad laid its third and fourth tracks with 65-lb. steel rails imported from England and France at a cost of $120 to $140 per ton, thus marking the increase from 60 to 65-lb. rail. Fig. 9, page 77, is a full-size reproduction of this section.

In 1873 a committee of the American Society of Civil Engineers, after studying particularly the wear of rails under the wheel-loads of that time (which were about 12,000 lbs.), concluded that it would be desirable for economic reasons to design what was termed a residual section, and then add enough metal on top to compensate for several years' wear. This idea found expression in many of the designs of that time such as the Pennsylvania Railroad standard, the Robert H. Sayre section, designed in 1875, and used on the Lehigh Valley Railroad; and is well illustrated in the New York Central 65-lb. rail of 1881, shown in Fig. 9, page 77. The type of section was thus materially altered by reducing the percentage of metal in the base and making a deeper head, supposedly contributing to the life of the rail; but in reality diminishing its

strength as a girder and causing eccentric shrinkage strains in the manufacture.

The first 80-lb. rail was designed by Dr. P. H. Dudley and was installed on the N.Y.C. & H.R.R.R. in 1884. As will appear from Fig. 10, page 76, it was characterized by a broad, shallow head, a well-balanced distribution of metal between head and base, and was slightly higher than the width of base.

100-lb. rail, designed by Dr. P. H. Dudley, was first rolled in 1892, and became the standard for the N. Y. C. & H. R. R. R., although 80-lb. rail was at that time standard on most of the trunk lines, and much of it was continued in use on the New York Central R.R. for many years subsequent to 1892. Fig. 5 shows the Dudley 100-lb. section as it is rolled today, slightly modified from the original design of 1892.

In the later 70's, at the solicitation of several railway presidents, Dr. Dudley began experiments to determine what improvements should be made in the track in order to permit higher wheel-loads and greater speeds. The light steel rails had enabled the railways to reduce the excessive cost of renewals of iron rails and track repairs generally; but they did not permit much increase in the wheel-loads or speed of trains. After travelling some 10,000 miles in his observation car over eastern railways, studying track conditions, Dr. Dudley became convinced that the 60 and 65-lb. rails were not stiff enough. Three forms of permanent set were found in practically all the rails then in use. Some were low at the joints and high at the center; some were low at the joints and center, and high at the quarter points; while others were wavy on the surface due to crude conditions of manufacture. There was insufficient bearing area on the tie also, attested by the rapid cutting of the

latter.

In 1881 Dr. Dudley had installed mechanism in his car for measuring the undulations of the track under the passing wheels. As a result of Dr. Dudley's investigations, the N.Y.C. & H.R.R.R. became the pioneer in utilizing heavy rails, the 80-lb. and 100-lb. rails following each other in less than nine years. It is interesting and of considerable importance to note that Dr. Dudley reduced the undulations of track on the New York Central R.R. from 8 1/2 ft. per mile in 1881 to less than 3 ft. in 1911, by increasing the section of rail from 65 to 100-lb. per yd. Dr. Dudley's theory was that the rail should be designed to act much as a girder by absorbing more of the duty itself, rather than readily transferring it to the ties and fastenings,aand that the undulations should be a minimum, thus reducing the train resistance so as to make possible greater train-loads at less operating expense. The Dudley 100-lb. rail embodies this principle.

Until 1893 there was no general standard rail-section on American railways. Each company had its own standard. In that year a committee of the American Society of Civil Engineers, after laboring with the problem for three years, reported a set of sections varying from 40-lb. to 100-lb. per yd., by 5-lb. increments, which were adopted by the society and soon were generally accepted by the railways.

Fig. 1, page 69, shows the 100-lb. A.S.C.E. rail. Each section has an equal height and width of base, and each has the same proportion of metal in head, web and base, 42%, 21% and 37%, respectively. The radius of tread was fixed at 12" in all sections, and the radius of upper corner of head at 5/16", while the radii of fillets was made 1/4". Between 1900 and 1908 about 75% of the railways in the

United States had adopted and were using the A.S.C.E section as a standard. The predominating weight of rail during this period was 80-lb. or under, while most of the trunk lines were using 90-lb. and about six or seven had installed 100-lb. rail.

The period from 1900 to 1908 witnessed an alarming increase in rail failures. The railways charged the failures to the manufacturers, asserting that the rails were rolled at too high a temperature and too high a speed, and that the manufacturers were sacrificing care for large tonnage. The manufacturers, on the other hand, charged that the failures were due to increased wheel-loads, increased density of traffic, less care in maintenance of track, specifying too high a percentage of carbon in order to get greater wear, and to the eccentric shrinkage stresses and non-uniformity of structure in the steel due to the inequality of area between the head and base of the A.S.C.E. section. The validity of these charges and the counter-charge will be discussed later.

A committee of the American Railway Association was appointed in 1905 to consider standard rail and wheel sections. A sub-committee, composed of representatives of the rail manufacturers, co-operated with the said committee in its labors. In 1908 after three years of careful study, the committee submitted its report recommending the adoption of two sets of standard rail sections, called the A.R.A."A" and A.R.A."B" sections. These were adopted by the Association and were later endorsed by the American Railway Engineering Association, the American Society of Civil Engineers and the American Society for Testing Materials.

The principal change made by the A.R.A. sections from the

A.S.C.E. sections was in the distribution of metal. The manufacturers held that the A.S.C.E. section had too large a percentage of metal in the head and too little in the base. Since the base possessed more cooling surface in proportion to its sectional area than did the head, it was urged that the latter had to be rolled at too high a temperature, producing soft, coarse-grained metal in the head where it was least desired. A further objection to the disproportion of metal was the excessive camber caused by the unequal shrinkage of cooling, which naturally required a large amount of cold straightening, with its accompanying dangers. These objections were held to be so valid that the new sections were designed with at least as much metal in the base as in the head, some of the new sections had more metal in the base than head.

The A.R.A."A" 100-lb. section is shown in detail in Fig. 2, and the "B" 100-lb. section is shown in Fig. 3. The better balance of metal between the base and head, is after all, but a very moderate difference from the A.S.C.E. section, while the other points of difference are even of much less importance, as will be more fully brought out in a later paragraph. The A.R.A. sections were not used until 1908, since which time their use has been continually on the increase; but in 1911 they constituted less than 10 per cent of all the rail in use on main lines.

Some of the trunk lines gave diligent and long continued study to the question of rails best suited to their own peculiar conditions of traffic, climate and roadbed, and have developed, as a result, sections which they have found it inadvisable to supplant. The more important of these are the New York Central Lines; Pennsylvania System; Harriman System; Northern Pacific; Delaware, Lack-

wanna and Western; and New York, New Haven and Hartford. Of these, the New York Central (Dr. P. H. Dudley) and Pennsylvania standards (Dr. C. B. Dudley) have probably received the most careful study of any rails in America, and they will be further discussed in the next paragraph. The others have but minor shades of difference from the main types, hence they will not be compared.

Comparison of the Principal Rail-Sections.

In Table 4 will be found a comparison of the physical properties of the A.S.C.E., A.R.A."A"., Dudley, A.R.A."B"., and P.S. 100-lb. rail-sections. Figs. 1, 2, 3, 4 and 5 are full-size detailed drawings of these sections. The casual observer will be struck by the relatively small divergence in shape or general dimensions of the five sections. A close study only confirms this opinion.

There are three general types of rails represented in this group, although the difference between them is comparatively slight. The Dudley and A.R.A."A" sections are known as the deep or girder type, while the A.S.C.E. section has some of the properties of both. The greatest variation in height in the five sections is 5/16", a modest difference. In the width of base a difference of 3/4" is noticed, the later sections showing the narrower dimension. It is conceded that the base is strengthened, in one respect at least, by reducing its width, as the "span" of the cantilever is thereby decreased; the thickness being increased to compensate for reduction in width. The Dudley section has the widest head, 3", Dr. Dudley holding the opinion that the strength of the rail against side thrust of the wheel-flange is thus augmented. The P.S. rail has the thickest head and the Dudley the thinnest, there being a difference

of 3/16". All sections substantially agree on the thickness of web. The radius of tread and radius of upper corner of head show too little variation to possess any practical difference.

Distribution of metal between base and head is of considerable importance. The Dudley and A.S.C.E. sections have a preponderance of metal in the head, the former having 6% more in the head. This would be a serious criticism of the Dudley rail if it were not for the high ratio of periphery to area of head. The A.R.A."A". section has the best distribution as there is almost 3% more metal in the base than head. The others have a nearly equal distribution. The ratio of cooling surface or periphery to area of head, web and base is an interesting comparison. The discrepancy between head (1.68) and base (3.10) of the A.S.C.E. section is noticeable, and yet the A.R.A."A" section is no better, despite the fact that this was the principal defect urged against the A.S.C.E. rail, the correction of which was the mission of the A.R.A. sections. The Dudley, A.R.A."B", and P.S. sections, however, give a much better account of themselves in this connection. The moment of inertia is considerably higher in the two girder sections than in the others; but little difference is apparent in the section modulus. All in all, there is not much difference in the properties of the several sections.

It is interesting to note the dates which mark the adoption of those sections we have been discussing, and to see the relation of each to the others. Dr. Dudley's 100-lb. rail was rolled in 1892 or just one year before the adoption of the A.S.C.E. section. The two sections have many, if not most, points in common. Fig. 11 is a full-size drawing of the two sections illustrating their points of similarity and difference. The difference of 1/4" in height is

by far the most noticeable one. As Dr. Dudley was a member of the Committee which evolved the "A" section of A.R.A. rail, and is reputed to have designed it, the very close agreement of the two in almost every particular, as shown in Fig. 12, is not surprising. The A.R.A."B" section is practically identical with the P.S. section, as will be evident from Fig. 13. The two were adopted at about the same time.

Fig. 14 is a comparison of the Dudley and the P.S. sections. These two represent the principal divergence of opinions regarding rail design. Dr. P. H. Dudley has proceeded on the theory that the rail should be stiffer, that it should itself support more of the load and impact with less dependence upon the supports. It would seem also that the idea has been to eradicate broken rails, as the climatic conditions along the New York Central main line are more severe than along the Pennsylvania. On the other hand the P. S. section seems to have been developed to cure especially a preponderance of head failures. If this be so, the main difference between the two types can be understood, even though both roads have much the same conditions of traffic. Of course the difference in chemical and physical specifications and thoroughness of inspection must be assumed to be a factor, although they will not be discussed here.

As for the question of the percentage of head failures, Table 1 gives the best information obtainable regarding the kinds of rail failures, taken from the statistics of the American Railway Engineering Association for the years 1909, 1910 and 1911. The figures shown therein are the general averages for practically all of the railroads of the United States, and so they are not necessarily representative of any particular road. Considerable variation

is to be observed in the several results, nevertheless a few important general conclusions are not to be overlooked. In the first place it is perfectly clear that the percentage of the several kinds of failures is not affected by the kind of steel, i.e. Bessemer or Open-hearth. About 55% of the failures are seen to be head failures, 25% are broken rails, 10% are web failures and about 10% are failures of the base. For a classification of the different kinds of failures see Fig. 7.

While it is evident that more than one-half of all our rail-failures are chargeable to head failures, it does not follow that this is the most dangerous form of failure. A failure of the head almost always develops gradually, giving external evidence of the impending break and making it possible to replace the rail before any considerable damage is done. The broken rail, however, is much more treacherous, for it seldom gives any warning before breaking, and of course it is most likely to fail under a passing train. The difficulty of obtaining the best metal in the head, due to conditions of rolling, and the very intense pressure sustained by the head, make it perhaps the most vulnerable part of the rail. It is not to be wondered at, therefore, that many efforts for rail improvement have dwelt largely with bettering the design of the head. The fact that the width of head has been increased only 3/8" in over thirty years (from 2 3/8" to 2 3/4"), while the wheel-loads have doubled, would at once make us suspicious of the adequacy of its design at the present time.

THE INCREASED DEMANDS UPON THE RAIL.

Perhaps the most common explanation of the short-comings of our modern rails has been that the wheel-loads, speed and volume of traffic have increased more rapidly than the strength of the rail. The inference has been, at the same time, that the rails of twenty or thirty years ago were entirely satisfactory, and while this is not true, we may well inquire into this phase of the subject with a view to determining how much greater the rail duty actually is, considering the many changes which have taken place in both the size of rail and the duty it has been subjected to.

The Increased Wheel-Loads.

In 1860 the wheel-loads of the heaviest locomotives were approximately 10,000 lbs. They underwent a gradual increase to 12,000 lbs. in 1873 and reached 15,000 lbs. in about 1885. From 1890 to 1900 there was a somewhat rapid increase to 25,000 lbs., and from 1900 to 1910 they were still further increased to 33,000 lbs., although the normal maximum now in use on most trunk lines is about 28,000 to 30,000 lbs. Thus the locomotive driving-wheel loads were doubled since 1885.

The number and spacing of drivers has not changed materially during the period under discussion. The increase in wheel-loads is naturally a result of the increase in the total weight of locomotive, but since we are primarily interested here with wheel-loads, the total weight of locomotives need not be discussed.

The increase in freight car and passenger car wheel-loads has been somewhat less rapid. The average freight car in 1887 weighed approximately 10 tons empty and had a capacity of 40,000 lbs., or 20 tons. The heaviest cars weighed 15 tons and had a capacity of 30 tons, making a maximum wheel-load of 11,000 lbs. The average weight and capacity of box cars have not increased much above the heaviest cars of 1887 as shown above; but since 1896 we have had the 50-ton capacity coal car, which gives a maximum wheel-load of 17,000 lbs. The number of wheels has remained the same (eight).

The heaviest eight-wheel passenger cars in use in 1887 weighed 70,000 lbs., making a wheel-load of 8,700 lbs. Today the heaviest steel passenger cars weigh about 160,000 lbs. and have a load per wheel of 13,300 lbs. Instead of an increase of 100%, then, in the wheel-loads of freight and passenger cars, as has been the case of locomotives, we see that they have increased only about 50% during the period from 1885 to date.

The Increased Speed of Trains.

Most writers have assumed that tho increase in speed of trains has kept pace with increased wheel-loads, and that the increased speed has been a large factor in causing rail failures. Many prominent engineers have subscribed to this view. While a comparison of the fastest trains of 25 years ago with those of today may not be an ideal basis for discussion, it will give us a fair idea of what the actual facts are.

In 1887 the New York Central Limited Express traveled from New York to Chicago, 960 miles, in 24 hours and 5 minutes, i.e.

at an average speed of 40 miles per hour. Nine American trains, (according to Wellington, p. 529), representing the fastest of that day, and including two of the long runs from New York to Chicago, averaged 41.7 mi. per hr. from terminal to terminal. The average distance between terminals was 374.5 mi. Omitting the two long distance trains, the other seven trains averaged 42.9 mi. per hr. for an average run of 214 mi.

The New York Central Railroad has operated its "Twentieth Century Limited" between New York and Chicago during the last seven or eight years on either an eighteen-hour or a twenty-hour schedule. The average speed in the former case is 53.4 mi. per hr. and in the latter 48.0 mi. per hr. The Pennsylvania "Broadway Limited" averages 50.5 mi. per hr. between the same termini. Aside from these two trains the average speed of the fastest trains is approximately 45.5 mi. per hour, as shown in Table 7. It is true, of course, that special trains have averaged almost 70 mi. per hr. for a single trip, and some of the regular trains average 50 mi. per hr. for short distances; but the average of present practice may be taken at 45.5 mi. per hr. This represents an increase of 2.6 mi. per hr., or only 4.8% over the average speed in 1887. Surely such a slight increase in the average passenger train speed cannot be responsible for any appreciable increase in the number of rail failures.

It may be argued that the average speed of the fastest trains is not a correct index of the maximum speed attained; but such a position is hardly tenable. While there is abundant evidence to show that such trains as the "Twentieth Century Limited" actually attain speeds of 90 mi. per hr., and even more at certain times,

it is only fair to assume that the trains of twenty-five years ago reached the same maxima. The increase in average speed which has been accomplished by such trains as we are discussing has been brought about largely through the elimination of stops. The elimination of stops has been due in no small measure to larger tenders, to the practice of taking water at high speed and to the numerous cases of track elevation through cities. It appears quite reasonable that the maximum speeds of the older trains were necessarily as high, if not higher than most of the present-day trains, owing to a lack of the foregoing improvements.

The local passenger trains often reach a higher maximum speed at certain points between stations than do the through trains, although figures are not available to prove the point. A very high speed is possible in the case of many local trains on favorable grades and track, because of the light trains and the greater excess of power required to pick up speed in a comparatively short time. This is probably more common now than formerly.

So far we have discussed the speed of passenger trains only, since they give the maximum speed in all cases. The fastest freight trains average as much as 25 or 30 mi. per hr., with a maximum of 50 mi. per hr. for very short distances. The ordinary freight train averages only 15 mi. per hr., which is no appreciable increase over the speeds of twenty-five years ago. Taking it all in all, there is no good reason to believe that freight train speeds have any direct bearing upon rail failures, except in the case of defective wheels and equipment or of excess counterbalance, which of course cannot be diagnosed, but are always with us to some extent. But some engineers who are in a position to know the facts, state

that the high speed freight trains actually damage the track more than the passenger trains on account of defective equipment.

Increased Density of Traffic.

Almost every writer upon the subject of rail failures has linked the increased density of traffic with a greater rail duty. The writer can find very little justification for this position. The life of a steel rail is measured by the number of tons of traffic which pass over it, providing that the speed and wheel-loads remain the same. If the amount of traffic be trebled, as it has in the past twenty-five years, a good rail would last only one-third as long as it did under the old traffic. Many railway managers have expected rails to last a certain length of time, say ten years, despite the greatly increased traffic; and perhaps their disappointment has fostered the general opinion above stated. Then again, it may be that due to this erroneous belief, rails have been permitted to remain in the track after the danger point of wear and punishment has passed, resulting in an excessive number of failures. Furthermore, if rails which used to last sixteen years now last only eight, due to increased traffic, and if the quality of the steel is the same, we should expect to find twice as many rail failures per year under the new conditions as we did under the old. There can be no doubt that a large share of the increased number of rail failures per year has been due to this one fact, which is really not a result of rail duty, nor can it be said to be caused by a poorer grade of steel.

Following is a summary of the evolution of the steel rail

and its duty during the last twenty-five years: 60-lb. rails were still generally used in 1887, under wheel-loads as high as 15,000 lbs. The maximum speed was substantially the same as at present. Ties were usually spaced 24" center to center. The maximum stress under these conditions using a dynamic augment of 200% as in the previous case and a section modulus of 6.7, was approximately 30,000 lbs. as compared with 21,000 lbs. under the present conditions with wheel-loads of 30,000 lbs. and 100-lb. rail. It seems to be a just conclusion, therefore, that the 100-lb. rails of today suffer no greater, and probably considerably less, unit stresses than the 60-lb. rails of twenty-five years ago. In other words if the 60-lb. rail was adequately strong for the rail duty then, the 100-lb. rail is fully as adequate for present - day conditions, assuming that the quality of steel is as good now as it was then. The increased rail duty has been shown to be principally a matter of greater wheel-loads, and the increase in weight of rail has fully compensated for this.

It must not be understood from the preceding discussion that all modern trunk-line railroads are using 100-lb. rail. As a matter of fact many of them are not, and therein lies one of the most fruitful sources of rail failures, particularly with 90-lb. rail. Those trunk-line railroads which have not installed 100-lb. rail use, as a rule, 90-lb. instead, under wheel-loads and speeds approximately as great as those roads using 100-lb. rail. The evils of this attempted economy are well shown in Table 2, where the failures of 90-lb. rail are seen to be almost twice as many per 10,000 tons as 100-lb. rail of either Bessemer of Open-hearth steel.

The percentage of 100-lb. rail in use on main-line track is less than 6% of the total. Table 8, following, shows the percentage of the various weights of rail in use on 244,496 mi. of main track in the United States, as of Jan. 1, 1912. It also shows the percentage of Bessemer, open-hearth, and special alloy steel rails in use at that time:

Table 8.

Percentage of Various Weights and Kinds of Steel Rails in use in Main Tracks, Jan. 1, 1912.

100 lbs.	5.84%
90 lbs. and less than 100	8.32
80 lbs. and less than 90	32.94
75 lbs. and less than 80	12.81
70 lbs. and less than 75	8.56
60 lbs. and less than 70	18.16
Less than 60 lbs. and unknown	13.37%
Total	100.00%

Bessemer	87.47%
Open hearth	11.43
Special alloy	1.10%
Total	100.00%

RAIL MANUFACTURE.

The Manufacturer's Attitude toward Rail Betterment.

For a good many years the railways have persistently accused the manufacturers of turning out an inferior grade of steel in their zeal to maintain record outputs, and have insisted that the manufacturers have not cooperated with them in a sincere effort to better the quality of rail steel. Much of this criticism of the manufacturer's attitude toward rail betterment, however, is founded on prejudice. The railways have exhibited a wonderful interest in rail manufacture, particularly within the last ten years; but they have always complacently assumed that the amount of metal in the rail was adequate. A good many ideas of doubtful value, imposing costly changes in methods on the part of the manufacturers, found their way into the specifications. In many cases the manufacturers refused to accept them, but no matter how unreasonable the changes were nor how ineffective they would have been in remedying defective conditions, the manufacturers were invariably accused of bad faith.

On the other hand some suggestions of undoubted merit were made by the railways which were not taken in good spirit by the manufacturers, largely due to the unhealthy feeling of distrust existing between the two parties, and also due to the preponderance of unfair and impractical demands of the railways. It is really not surprising that the two parties could not agree under such conditions. Not until the last few years, when by a careful, scientific study of the details of manufacture, have the railways been able

to convince the manufacturers that there was any real good to be derived from a greater cooperation. Even now there is a strong under-current of feeling with the manufacturers that the railways are interested only in improving rail manufacture at the manufacturer's expense, and that no attention will be given to the question of proper design and care of the rail. Both sides are in some measure to blame for this unfortunate situation, the railways more than has been generally understood.

It is well known that interlocking of directorates has sometimes existed between the railways and steel companies. The objection has been raised that this practice is inimical to securing the best rails in certain cases. Now it must be apparent this is not an inherently bad influence. The presence of a railway director on the board of directors of a steel company ought to make for a better understanding between the two parties, and, if any prejudice exists, it should be in favor of better rather than worse rails for the railway company so involved.

Increased Tonnage Manufactured.

It has already been stated that one of the charges against the manufacturers has been that of carelessness growing out of the rush incident to constantly increasing rate of output. In Table 6 is given the yearly rail output from 1886 to 1913. It will be apparent from these statistics that increased production of rails has not by any means been a mushroom growth; but on the other hand it has been fairly steady and uniform. The years 1887 and 1906 seem to have been abnormally high, but not so much so as to indicate an

alarming overcrowding of the mills. The building of new mills and the improvements and enlargements of old mills have at least kept pace with increased requirements of production. The constantly increasing weight of rail must not be overlooked in considering this phase of the subject. Some of the increased tonnage can be ascribed to increase in weight of rails rolled, and this, of course, lessens the apparent or arithmetical difference between production during successive years.

While the relation between rail prices and quality is practically impossible to analyse, some importance has been attached to the alleged tendency to fix the price of rails, as showing improper and unlawful collusion between the manufacturers. If such a condition has actually existed there is little reason to believe that the quality of steel in rails would thereby suffer any more than would the quality of other steel. No deterioration has been charged against other kinds of steel from this cause, so it is probably unfair to say that rails have been so affected. The price of Bessemer steel rails has been reduced from $150.°° per ton in 1868 to $20.°° per ton in 1898, while since 1901 it has remained approximately stationary at $28.°° per ton. No good reason is apparent for believing that $28.°° is an excessive price per ton, nor is it at all clear that a stationary price has been accompanied by a diminution in quality.

Perhaps the oldest known defect in ingots is the pipe. This is a small shrinkage cavity which sometimes forms in the top central part of the ingot as it cools from the molten state. An effort is made to eliminate the pipe by cutting off and discarding

the top portion of the ingot, but since the pipe forms lower down in the ingot at times, it is not always contained in the discard. When the ingot is rolled the pipe is lengthened so that it may be several feet long in the finished rail. Oftentimes it produces no failure, as it may be present in such a way as not to weaken the rail to any great extent. When it does cause a failure, the defect is usually apparent for sometime in advance, a dark spot appearing on the surface of the rail. The pipe is not a particularly dangerous type of defect for this reason.

Segregation is one of the most uncertain and discouraging influences in rail manufacture. It occurs usually in the top one-third of the ingot, and often it is confined to the top 20%. The carbon and phosphorous, as well as the other elements, become concentrated in the top middle portion so as to produce steel of radically different properties than that desired. Surrounding this region is usually a zone of negative segregation, which further complicates the danger. Segregation may exist as much as one-half way down the ingot although the worst conditions almost always occur near the top. The normal content of phosphorous, carbon or sulphur is often increased from 100 to 400%, and of course this part of the ingot must be discarded. The principal difficulty is in determining how much to discard.

The Wage System and Its Effect on Quality.

The present wage system prevalent in rail mills cannot be said to be a contributing factor in securing good rails. In many mills the men immediately in charge of the manufacture are paid a certain salary, plus an amount or bonus contingent upon the tonnage

manufactured. It is customary to deduct for rejected product. The operator of a gagging machine may feel the rail "give" under the machine, and he may be thoroughly satisfied that he has injured the rail, and still he will probably not report the matter. As a result the rail will likely find its way into the track, already strained beyond its elastic limit, and almost certain to fail later under a passing train. The burdens placed upon the inspectors of rails are thus unnecessarily and unfairly augmented.

Segregation and Pipe in Ingot.

The production of sound ingots has lately been the subject of much discussion. No one has yet been able to trace defects in the steel any further back in the process of manufacture than the ingot; but enough defects have been found in the ingot to make it a veritable battle-ground of opinion regarding better steel. The production of sound ingots is probably the most difficult and the most important operation in the entire process of manufacture. Whatever defects are cast in the ingot appear unchanged or augmented in the finished rail, and herein lies the necessity for sound ingots.

Blow-Holes and Transverse Fissures.

In addition to the pipe and segregation which make the top of the ingot unsound and unreliable, blow-holes and slag spots add further to the uncertainties. The blow-holes are caused by entrained gases. They occur at irregular intervals throughout the top, and of course, make for unsoundness.

The transverse fissure which develops in high carbon rails from small slag spots in the head of the rail is without doubt the most dangerous type of failure yet known. It appears to start from a minute beginning and then grows radially or in annular rings under traffic, until, withoug warning, the rail gives way. As far as is known the transverse fissure is concomitant with high carbon and brittleness. Little was known of it until the fatal Manchester wreck on the Lehigh Valley Railroad in 1911. Several other wrecks have been traced to the transverse fissure; but no cure for it has yet been found.

Percentage of Discard.

It is generally conceded that a discard of 33% would do away with a large share of rail failures, perhaps as much as one-half of them, as about one-half of all failures occur from rails rolled from the top 33% of the ingot. The manufacturers, however, have never been willing to adopt an abitrary discard of such a large percentage without increasing the price of steel. The amount of discard which has actually prevailed for many years has been from 10 to 15%. Rail experts have differed radically on the question of a specified discard. The Pennsylvania Railroad and some of the other roads noted for their careful study of the rail question, have long held the position that no abitrary specified discard will insure sound rails. The amount would necessarily vary at the different mills. They have simply specified that enough of the ingot should be cropped to give sound steel, and then they have made the drop-test specification so rigid that it would be impossible to pass unsound

or segregated rails. As the entire heat is rejected or accepted according to the test made from a specimen taken from the top of the ingot, or region of poorest metal, the manufacturer has assumed the obligation of discarding the unsound metal and of course has found it to his own advantage to make the amount of discard sufficient. The best specifications have adopted this idea.

Size of Ingot.

The smallest ingot for 100-lb. rail is that specified by Dr. Dudley, who will not permit the ingot to contain more than three rails each 33 ft. long. Such an ingot weighs about 3900 lbs. The largest ingots for 100-lb. rails weigh about 12,500 lbs., from which eight rails are rolled after discarding the top 20% of the ingot. Mr. M. H. Wickhorst, in his tests upon the relation between segregation and other rail properties and the size of ingot, as reported in Bulletin # 151 of the American Railway Engineering Association, found that neither the segregation nor the ductility are greatly influenced by the size of the ingot. Ingots varying from 12 x 12 inches to 25 x 30 inches in cross-section were tested. The evidence seems to be that ordinary variations in the size of ingot are not responsible for any appreciable variation or defect in the quality of steel.

Method of Pouring.

The tendency to pour larger heats, particularly within recent years, is undoubtedly a harmful influence, particularly with the open-hearth process. Some of the heats now approach 100 tons,

and in order to pour such a large mass from a single ladle before it freezes, the diameter of nozzle is made quite large. By the time the last of the metal is poured into ingots the hole has probably enlarged to almost 2 1/2", and such a large stream causes a great deal of splashing and washing up the sides of the mould. Surface defects are likely to be caused by this practice, and probably many rail failures have resulted therefrom.

Recent Improvements in Ingot Casting.

Much progress is being made toward producing sound steel by better practice in casting the ingots. Leading metallurgists throughout the world are devoting great energy to the question, and already several improvements of promise have been suggested, which are being tried out. The use of thermit is claimed by Dr. Hans Goldschmidt to eliminate the pipe and blow-holes, while Sir Benjamin Talbot has proposed the use of aluminum in small quantity and then compressing the top of the ingot while still liquid in the center. Sir Robert Hadfield has invented a process of keeping the top of the ingot in a liquid condition during the cooling and shrinkage of the metal below, which also is receiving considerable attention. It is very apparent that we may reasonably expect the near future to witness changes in the present methods of ingot casting which will go a long way toward producing sounder rails.

Rolling of Rails.

There have been several mooted questions connected with the rolling of rails, the most important being the speed of rolling, the temperature of steel at the last pass, and the unequal velocities

at which different parts of the section are rolled. None of these has ever been proved to be of any serious consequence. Coincident with the increasing tonnage manufactured and the increasing number of rail failures, it was affirmed by the railways that the manufacturers were increasing the capacities of their mills by increasing the speed of the rolls; when as a matter of fact only the speed of the roller tables between passes had been increased to any considerable extent.

Temperature of rolling was, until recently, generally held to have a deciding influence upon the quality of steel. Tests made during the last year by Mr. M. H. Wickhorst, engineer of tests for the American Railway Engineering Association, prove that ordinary variations in temperature of rolling exert but a very slight influence upon the properties of steel rails. No data exist to show that rail failures have in any way been connected with the temperature at which the rails were rolled. Arguments to this effect have been based principally upon speculation.

A difference in radius of as much as 2 1/2" sometimes exists between the part of the roll which rolls the web and the part which rolls the side of the flange. The unequal velocities of the several parts of the rolls have been said to cause a slipping of the fibres, with a consequent injury to the structure of the metal. Inasmuch as the rolling of other sections, such as angles and wide flanged I-beams has never been found defective in this respect, a reasonable conclusion appears to be that rails do not suffer from this cause.

On the whole, then, we may safely conclude that the rolling of rails as now practiced is in no way detrimental to the quality

or soundness of the metal.

Straightening.

The exact effects of cold straightening of steel rails have never been determined. Reference already has been made to the possibility of straining the rail beyond its elastic limit in the straightening or gagging machine. In many cases during the last few years rails have been heard to snap under gagging, and this has led to a clause being inserted in some specifications rejecting all such rails. Of course this provision requires an inspector's exclusive attention; but it is justified under present conditions. Any change in the rail section or in the cooling which will eliminate the amount of straightening required, and any change in the wage system which will make the machine operators more zealous in reporting rails which they know to have been ruined, should be welcomed.

Handling.

The manufacturers have been charged with careless handling of the rails, principally in loading. It has been said that the rail is dropped into the cars from a height of four or five feet and that the rail is likely to be injured thereby. Some railway engineers have taken the position that the rail is made for rough service, and that if it is well-made it cannot suffer injury by falling from such a height. It is extremely difficult to cite specific cases to prove the assertion; but it certainly seems reasonable that more care should be exercised in handling rails, not only at the mills, but in unloading from cars on the track as well. We know that a rail may be broken off clean by making a chisel-mark across

the rail and dropping it across a block. While most rails are perhaps not injured in loading or unloading, there must be many cases where injury does occur. The idea that a rail is beyond injury is not a safe rule for the guidance of laborers in handling them.

Open-Hearth vs. Bessemer Steel.

It has already been shown that open-hearth steel is being specified to the exclusion of Bessemer steel for rails, in so far as the capacity of the mills are able to make the change, owing to the fact that open-hearth steel rails have proved to be more reliable. It is well known that phosphorous may be reduced as desired in the basic open-hearth process through the agency of the lime flux, whereas our high phosphorous ores do not permit less than 0.10 per cent phosphorous in acid Bessemer rails. Moreover, there are some reasons to believe that open-hearth steel possesses superior physical characteristics aside from those resulting primarily from its chemical constituency. At any rate the tendency toward open-hearth rails is unquestionably a commendable one; the only question being in the degree of superiority.

Regarding the comparative performance of Bessemer and open-hearth rails, too definite conclusions should not be drawn. In a subsequent paragraph under rail failures, statistics will be given showing that there are about twice as many failures with Bessemer as with open-hearth rail. These figures, however, are based upon old Bessemer rail and comparatively new open-hearth rail. As the ratio of failures is increasing in the case of open-hearth and decreasing with Bessemer, it may be that as the open-hearth rail grows older its performance will approach that of the Bessemer.

Special Alloy Steels.

A good many efforts have been made to improve the wearing qualities and strength of rails by resorting to titanium, vanadium, nickel-chromium and other alloys, both in the open-hearth and the Bessemer process. While the wearing qualities in most cases have been increased, little has been accomplished in the way of reduced failures. That this is so is not surprising as we have already seen that the greatest defects in the rails lie in the insufficient mechanical properties of the rail itself and in the unsound metal resulting from methods of casting the ingot. Possibly certain alloys will someday be found which will guarantee us better rails than we have yet been able to obtain; but as yet, we are in the experimental stage.

SPECIFICATIONS.

Physical Requirements.

The drop-test is perhaps the most important test prescribed for rails. It has been described by some as brutal and unscientific; but it is the most effective agency in eliminating defective or brittle steel that has yet been devised. In recent years, chiefly due to the studies of Dr. P. H. Dudley, it has been developed to the point where it also serves as a measure of ductility.

Considerable progress has been made in applying the drop-test. Not more than a decade ago the manufacturers often selected the test specimen from either end of the ingot, since the specifica-

tions did not always specify which end should be used. In other cases the best-two-in-three principle governed the selection or rejection of a number of heats. The idea seems to have been to accept as many heats as possible, rather than to see that only good rails were accepted. Sometimes only one heat in five was tested. The drop-testing machines were not standardized and although the weight of the tup and height of drop were specified, nothing was said about the weight of anvil nor the method of supporting it. As a result the anvil was found to weigh only 3,000 lbs. in some cases, whereas it is now required to weigh 20,000 lbs. As far as the physical requirements will reveal unsound or unsatisfactory steel, there are abundant reasons to believe that we are getting a better and more reliable grade of steel today than formerly. Three test specimens are now taken from each heat, one from each of five ingots, and are subjected to the drop-test under the most stringent requirements that could be devised. A few engineers have advocated testing every ingot; but it is extremely doubtful if such procedure would be any improvement over the present practice.

Chemical Requirements.

Although the chemical constituents of steel rails have less influence upon rail performance, within reasonable variations, than they have been generally credited with, the changes during the last ten years, particularly in the adoption of open-hearth steel, have been for the better. It may be said that the chemical requirements now specified for basic open-hearth steel rails are as near perfect as the present state of metallurgical knowledge permits. The realization of these requirements is, however, less certain. We are

not yet able to eradicate segregation and other defects of manufacture completely, but progress is being made in this direction which should give uniformily better results in the future.

Bessemer steel has suffered a retrogression of late years, due to the high phosphorous ores. Formerly the phosphorous was limited to 0.08 per cent, but a few years ago it became necessary to fix the limit at 0.10 on account of the low phosphorous ores becoming exhausted, which, of course, increased the possibilities of brittleness in the rails, and hastened the change to open-hearth steel.

Details of Manufacture.

A good deal of improvement has been made in recent specifications in the details of manufacture. By specifying the maximum allowable amount of shrinkage after the rail leaves the hot-saws, it is guaranteed that the rail is not finished at too high a temperature. By ruling out the holding of the rail for the purpose of reducing its temperature during rolling, or of artificially cooling it in any other way, an additional precaution was taken. Another progressive measure was in limiting the amount of camber, which insured that only a reasonable amount of straightening would be required in the gagging machines.

INSPECTION.

In no respect has greater progress been made toward better rails than in the matter of inspection. Until 1912, excepting possibly two or three railroads, rail inspection was carried out by

one or two inspectors, that is, the manufacturers were intrusted with most of the inspection. The impractibility of one inspector giving adequate inspection to the various tests and details of manufacture of three rails every minute for a period of twelve hours must be apparent. Most of the railroads now turn the inspection over to an inspection bureau, which usually has a corps of some ten or fifteen inspectors on the work continuously. Much better attention is being given to every detail of the manufacture and tests than formerly. In so far as adequate inspection is a factor in insuring that the specifications are carried out, the rails of today should be superior to those of years gone by, assuming the same attitude on the part of the manufacturers now as then. The information gained from a closer study of the numerous details by the inspectors also should be no small factor in eventually securing more perfect requirements.

TRACK CONSTRUCTION AND MAINTENANCE.

If there is any important phase of the subject of rail failures which has received but scant scientific attention it is track construction and maintenance. Little data exists upon which definite decisions may be based, although we are able to say that certain conditions have been improved, while one or two others have shown a lack of conservatism which is really surprising.

Ties.

Timber ties have been the standard of American railways for more than sixty years. In providing a support for the rail

which is not too rigid but permits of a sort of cushioning effect, no material yet suggested offers any improvement over timber. While there has been a slight decline in the general size of timber ties, this has been more than offset by a closer spacing. At the present time the spacing of ties is as close as practicable on trunk-line railways. If more ties were employed insufficient space would be left between them for proper tamping. There is no reason to suspect that the number of ties is not sufficient for modern conditions.

Tie-Plates.

The increasing use of tie-plates during the last ten years has been accompanied by some disadvantages. Most of the half-moon base failures have occurred over ties, and, in many cases, over tie-plates. Perhaps the rail is subjected to greater shock, or rather absorbs more of the shock, over a tie-plate than it does without the tie-plate, or perhaps the trouble may be the result of a poorly designed tie-plate. The writer has traced several base failures to a tie-plate having a shoulder against the outside of the base of the rail, which finally, due to the tie-plate's becoming loose on the spikes, worked under the rail at one end in such a way that it left the rail supported on a very small area, and soon resulted in a failure. The tie-plate should, however, insure a better and more uniform bearing for the rail; so that taking it all in all, it is probable that the net result of tie-plates has been to reduce rail failures.

Joints and Fastenings.

The railways have made commendable progress during the last twenty-five years in improving and strengthening the joint. The percentage of rail-failures in the region of the joints is no longer excessive in first-class track. By using long six-bolt splices with a three-tie support such roads as the Pennsylvania, New Haven, and New York Central, with the heaviest of wheel-loads, highest of speeds and densest traffic, have been able to so perfect the joint that, under normal conditions, it produces no jar or other evidence of its presence to passengers. An immense amount of study has been given to the question of improving the method of splice, and it is gratifying to note the progress which has been made.

Ballast.

Rock or "broken-stone" ballast is conceded to be the best ballast now obtainable as it best performs the several functions of holding the tie in place, distributing the load to the subgrade and quickly shedding water. The uniformity with which stone ballast has been adopted by the trunk-line railways is an evidence of marked improvement in track construction during the last twenty years. The question of adequate thickness under the tie may be a matter for discussion, but we must be content here with the conclusion that the railways have been diligent in improving the ballast, and that present practice in ballasting is at least approximately equal to the needs.

Subgrade.

The great foe of good subgrade is water. The railways have recognized this fact by introducing subdrains and larger ditches in cuts, during the last twenty years. As the subgrade is after all the foundation of the track, the importance of keeping it dry and solid is not to be overestimated. Rail failures due to rough track in wet cuts have taught their lesson, and it is only fair to say that the railways have made splendid progress in correcting this evil.

Track Maintenance.

It is to be regretted that it is not possible to present statistics comparing the amounts spent in track maintenance during the last twenty-five years. Generally speaking, however, few indeed will question the statement that railway track is better and more carefully maintained now than it was ten or twenty years ago. Of course stone ballast and heavier rails tend to reduce the cost of maintenance, but this in no way lessens its quality.

The most pernicious practice in track construction or maintenance, and perhaps one of the most dangerous influences that the rail is subjected to in its entire existence, is the method of renewing ties which has always characterized American practice. The ties are renewed at random, i.e., any tie which becomes decayed or unfit for further service during the year is marked for renewal during the following summer. It matters not if every third tie, every fifth tie or every twentieth tie is so marked; the ballast

is dug out around the tie and after the tie has been replaced by a new one, the ballast is put back and an attempt is made to tamp it solid so that the original condition of the track will be restored. The chances of being able to reproduce the former conditions without the use of any instruments excepting the foreman's eye, are exceedingly remote. What actually occurs is that the tie is left too high or it soon settles as the ballast cuts into it from the bottom, and the rail is subjected to unusual and ever-changing stresses.

The unscientific method of maintaining the surface of the ties, or rather the supports for the rail, is a severe reflection upon the railways of this country. No other structure would be permitted to rest upon such insecure and uncertain supports without a most liberal factor of safety, and then only in case of absolute necessity. Necessity has not even dictated this unfortunate practice, as it is entirely practicable, though less economical, to lay and renew ties by sections. Until the latter practice prevails, rail failures can be eliminated only by perfect steel and an unnecessarily large factor of safety.

RAIL FAILURES.

Analysis of Statistics.

For the last three years the American Railway Engineering Association has collected and published annually statistics from most of the American steam railways showing considerable data regarding all main line rail failures. The information shown in Tables 1, 2 and 3 is compiled from these statistics. It must be borne in mind that since these figures are the averages of all the

railroads reporting, they are not necessarily typical of any particular railway. Conditions of roadbed, character and density of traffic, and other conditions make the results vary a great deal, although some important conclusions may be deduced therefrom. In Fig. 7 will be found a classification of the more common types of failures. The personal equation must tend to produce some non-uniformity in reporting the kinds of failures; but since all trackmen report the failures on the same forms and from the same instructions, it is felt that the personal equation is reduced to a minimum.

Percentages of Different Kinds of Failures.

Table 1, showing the percentage of different kinds of rail failures, has already been referred to on page 27 where it was shown that about 55 per cent of all failures were in the head, about 10 per cent were in the web, about 10 per cent were in the base and about 25 per cent were broken rails. Much variation exists from these averages, but the general statement that one-half of all rail failures are due to head failures and one-quarter are due to broken rails, is correct. A good many head failures are due to piped rail, while a large proportion of rails fail by crushing or flowing of metal. It is noticeable that on the whole, practically the same percentages exist in Bessemer as in open-hearth rails, and the weight of rail appears to have little if any influence upon the proportion of the several kinds of failures. The great excess of failures due to broken rails and defective heads would seem to indicate that the trouble lies in one of two directions: (1) Either the wheel-loads and speeds are abnormally high for the size and design of the

head and the rail in general; or (2), the steel possesses inherent defects of manufacture. Either of these is a sufficient reason for increasing the factor of safety by increasing the amount of metal in the rail.

Order of Superiority of Various Rail-Sections.

Table 2 is a very interesting comparison of the order of superiority of the principal sections of Bessemer and open-hearth rails of different weights, based upon the relative number of failures per 10,000 tons of rail in use during the years 1910 and 1911. Here again we observe many inconsistencies; but in a broad way we cannot overlook a few important comparisons. In the first place we note from the summary at the bottom of the table that Bessemer rails show almost twice as high a rate of failure as open-hearth. With the 100-lb. and 90-lb. sections the Bessemer failures are almost three times as much as open-hearth. Of course we must recognize the disparity between the total amounts of rail which we are comparing. Since the amount of Bessemer is approximately five times the open-hearth, the Bessemer figure is the more reliable. The fact that the open-hearth rail is mostly new, while a good deal of the Bessemer is old, also lessens the force of the comparison. It will be noted in the summary that the rate of failure of Bessemer declined three points from 1910 to 1911, while open-hearth increased three points. This would suggest the thought that as the open-hearth rail grows older its rate of failure will more nearly equal that of the Bessemer. On the other hand the tendency to use open-hearth rail as an experiment on curves and in those places where Bessemer rail has given the poorest service, may make the comparison

of performance during past years somewhat unfair to the open-hearth.

The very high percentage of failure shown for the 90-lb. Bessemer rail is fair proof that the 90-lb. track is being subjected to unreasonably high duty. As a matter of fact much of it is actually carrying the same loads and suffering the same amount of punishment as some of the 100-lb. track.

The records of the re-rolled rails are not properly comparable in this table, since it is more than likely that those rails containing the most glaring defects of manufacture had been eliminated before re-rolling. Even waiving this handicap, however, the two cases of re-rolled Bessemer rails shown do not completely justify the predictions made in their behalf for main track service.

Comparison of Failures of Principal Sections of Heavy Rail.

Table 3 has been compiled from Table 2 for the purpose of showing more clearly a comparison of the performance of the heavier sections of the principal types of rails, (shown in Figs. 1 - 5). One or two points of particular significance are shown in this table. The most striking fact is the favorable record of the A.S.C.E. sections compared with those of the A.R.A. Excepting the 90-lb. rail, the A.S.C.E. sections actually show a lower rate of failure than the A.R.A., notwithstanding that the A.R.A. rails in all cases are newer, and the tonnages on which their performance is based are only from 1/2 to 1/40 of those of the A.S.C.E. Even the 90-lb. A.S.C.E. Bessemer rails prove superior to the A.R.A."B" rails. The total

average percentage of failure for the A.S.C.E. rail is lower than the A.R.A."B" section for both Bessemer and open-hearth steel, and is almost as low as the A.R.A."A" section.

After all, Table 3 shows us what we have already concluded from a comparison of the several types of sections, p. 24, et. seq., i.e. that there really is very little difference in the properties of the various sections. The only rail which shows a creditable and at the same time a consistent rate of failure is the P.S. section. In every case it is below the average and at the same time it shows less fluctuation than the others. The fact that this section is so much like the A.R.A."B" section, as shown in Fig. 13, should incline us toward the opinion that the difference between the performance of the two lies in the better specifications and inspection which govern the manufacture of the Pennsylvania's rails.

The remarkably low rate of failure of Dr. Dudley's open-hearth rails is a very recent development, and is in marked contrast to the same rails of Bessemer steel. We may well await further proof of the unusually good performance of these rails, as the small tonnage and recent rolling may not give us a fair comparison.

Failures According to Position in the Ingot.

In Table 9, below, is given a summary showing the percentage of failures for both Bessemer and open-hearth steel, according to the position of the rail in the ingot, A being the top rail. The statistics are from those of the American Railway Engineering Association for the year 1911.

TABLE 9.

Summary showing Percentage of Rail Failures According to Position in Ingot for the Year 1911.

Kind of Steel.	Percentage of Failure at Each Position in Ingot.					
	A	B	C	D	E	F, etc. Total
Open-hearth	22.9%	19.6	17.5	14.8	13.0	12.2%	100%
Bessemer	43.7%	16.1	23.7	10.7	4.3	1.5%	100%

The uniformity of failures throughout the entire open-hearth ingot shows that there is little to be gained by increasing the discard by any reasonable amount. In the Bessemer ingot, however, it is clear that if these percentages can be relied upon as average conditions, the "A" region should be included in the discard. It hardly seems possible that such a difference between the open-hearth and the bessemer ingots is a normal condition; but if the high rate of failure in the "A" region is verified by subsequent experience with Bessemer ingots, the railways could make no more positive and certain advance in reducing rail failures, than to insist upon a greater discard until improvements in the methods of ingot casting will eradicate the difficulty. The trouble is not so important now as it was some years ago, though, for we have seen from Table 5 that more open-hearth rails are now being rolled than Bessemer, with a rapidly increasing proportion of open-hearth each year.

SUMMARY.

Following is a summary of the reasons advanced for the inadequacy of the steel rail under present-day conditions:

1. The factor of safety in American rails, considering the wheel-loads, speed, effect of counterweight on locomotive drivers, inherent roughness of track, inherent defects in the steel itself due to conditions of manufacture, temperature stresses in the rail, constant reversal and repetition of stress, defective equipment and unscientific methods of track maintenance, particularly in renewing ties, is now, and has been for many years, too low.

2. In the evolution of the steel rail previous practice appears to have been given too much importance as a guide to correct design.

3. Instead of sufficiently increasing the mechanical properties of the rail in advance of increased wheel-loads and increased duty, the latter have been permitted to precede the former.

4. The railways have been somewhat lax in their efforts to secure proper data for bettering the design of the rail.

5. Several of the essentials of good track, viz., the joints and fastenings, the ties, the tie-plates, the rock ballast and the drainage of the subgrade, have been improved in the direction of making a more uniform and a more stable support for the rail.

6. The manufacturers, responding to more stringent demands and inspection on the part of the railways, and also through

improvements in processes and details of manufacture, have produced in late years a better grade of steel than formerly.

7. Some defects of manufacture have as yet been beyond control, and have made the quality of steel somewhat non-uniform. These defects, under the ponderous rail-duty of recent years, have become more and more apparent.

8. The open-hearth process is rapidly replacing the Bessemer process in rail manufacture. A decrease of fifty per cent has thus far been effected thereby in the rate of rail-failure; although there are good reasons to believe that the final figures will prove less encouraging, unless some much-needed improvements are realized in rail manufacture.

9. Statistics of rail failures show conclusively that attempted improvements in the section of rail have not yet been successful in lessening the rate of failure.

10. Statistics indicate that almost one-half of all Bessemer rail failures occur in steel rolled from the top twenty-five or thirty percent of the ingot; although the percentage of failures from the top of the open-hearth ingot is almost normal.

CONCLUSIONS.

The conclusions given below summarize the changes which, in the writer's judgment, should be made by the railways and the rail-manufacturers, on account of the defects in present-day steel rails which are indicated in the preceding pages:

1. The maximum speed of all trains should be limited to sixty miles per hour under present track conditions on American railroads.

2. The shape or dimensions of the rail-section should be increased so as to give a factor of safety of at least ten in the working unit-stress.

3. More intensive study should be made of the actual stresses rails are subjected to under ordinary operating conditions.

4. A discard of at least twenty per cent of the Bessemer ingot should be made until such time as improvements in rail manufacture make it no longer necessary.

5. No further increase in wheel-loads should be permitted until the rail, as a structure, is better able to withstand safely and adequately the duty it is already called upon to bear.

6. Present methods of renewing ties and maintaining track should be supplanted by methods which will produce a minimum instead of a maximum disturbance to the ties and track foundation.

TABLE I

Kinds of Rail Failures with Different Weights of Rail for Bessemer and Open-Hearth Steel, Years 1909, 1910 & 1911.

[Abstracted from Statistics of the American Railway Engineering Ass'n.]

WEIGHT OF RAIL IN LBS. PER YD.	YEAR	PERCENTAGE OF EACH KIND OF FAILURE.							
		BROKEN		HEAD FAILURE		WEB FAILURE		BASE FAILURE	
		BESS.	O.H	BESS.	O.H.	BESS.	O.H.	BESS.	O.H.
100	1909	20	19	58	41	14	28	8	12
100	1910	34	23	47	56	9	13	10	8
100	1911	32	31	51	45	11	20	6	4
90	1909	17	34	74	51	6	12	3	3
90	1910	24	38	58	46	9	11	9	5
90	1911	21	42	62	41	6	9	11	8
85	1909	16	21	70	64	6	9	8	6
85	1910	30	21	53	63	5	11	12	5
85	1911	28	24	53	53	6	11	12	12
80	1909	16	15	73	60	6	19	5	6
80	1910	23	34	67	44	6	12	4	10
80	1911	21	28	67	38	6	8	6	26
75	1909	28		52		18		2	
75	1910	32	35	49	30	12	14	7	21
75	1911	25	59	52	5	17	7	6	29

A.F.C.

Order of Superiority of the F
and Open-Hearth Steel ; Bas

[Compiled

	BESSEMER			
	1910			
	SECTION	TONS LAID	FAILURES PER 10,000 TONS	SE
1	N.Y.N.H.&H.	29,979	5.0	P.R.
2	A.R.A. "B"	81 235	12.4	A.R.
3	P.S.	75 591	16.3	P.S.
4	P.R.R.	433 405	18.7	DUDL
5	P.&R.	8 900	32.6	A.S.
6	A.R.A. "A".	11 165	33.1	P.&R
7	A.S.C.E.	654 572	36.6	N.Y.
8	DUDLEY	179 647	50.6	A.R.
9				
	TOTAL =	1,474.494	MEAN: 30.1	
1	A.R.A. "A"	60,546	17.2	A.R.
2	G.N.	46 500	21.5	A.S.
3	D.L.&W	4 192	43 0	RERC
4	A.S.C.E.	885 635	61.3	C.S.
5	C.S	113 486	67.4	A.R.
6	A.R.A. "B"	121 465	92.0	G.N.
7				
		1 231 824	61.0	
1	M.P.	122,120	5.7	O.R.
2	P.R.R.	609 279	17.5	P.R.
3	P.S.	94 965	29.3	A.R.
4	A.S.C.E.	2 676 902	35.4	M.P.
5	C.B.&Q.	266 745	57.6	P.S.
6	A.R.A. "A"	1 964	112.0	A.S.
7				C.B.
8				C.P.
		3 771 975	33.0	
1	A.R.A. "A"	7 508	0	A.R.
2	DUDLEY	275 495	16.5	C.S.
3	A.S.C.E.	1 762 850	26.5	RERC
4	CAMBRIA	3 708	45.8	DUDL
5				A.S.
6				CAMB
		2,049,561	25.1	
1	M.P.	73 477	2.9	P.R.
2	P.R.R.	1 563	12.8	M.P.
3	B.&M.	37 063	13.2	A.S.
4	A.S.C.E.	645 019	21.0	O.R.
5	C.S.	312 435	44.1	C.S.
6				B.&M
		1,069,957	28.2	
	Grand total for 1910: 9,600,000 tons; 34.0 failures per 10,000 tons; 1 failure per 812 rails or 1 failure per 2.3 miles of track.			Grand failures or 1 fai

A.R.A. "A" - Am. Ry. Assn. Type "A".
A.R.A. "B" - " " " " "B".
A.S.C.E. - Am. Soc. C. E.
B.&M. - Boston & Maine

CAMBRIA - Cambri
C.B.&Q. - Chicago
C.P. - Canadian Pa
C.S. - Common Stand

A.F.C.

TABLE 2

Order of Superiority of the Principal Rail Sections of Different Weights, for Both Bessemer and Open-Hearth Steel; Based upon Relative Number of Failures During the Years 1910 & 1911.

[Compiled from Statistics of the American Railway Engineering Ass'n.]

	BESSEMER						OPEN HEARTH					
	1910			1911			1910			1911		
	SECTION	TONS LAID	FAILURES PER 10,000 TONS	SECTION	TONS LAID	FAILURES PER 10,000 TONS	SECTION	TONS LAID	FAILURES PER 10,000 TONS	SECTION	TONS LAID	FAILURES PER 10,000 TONS
						100-LB.						
1	N.Y.N.H.&H.	29,979	5.0	P.R.R.	464,825	16.9	A.R.A."B	19,565	1.0	D.L.&W.	12,770	0.0
2	A.R.A."B"	81 235	12.4	A.R.A."B"	137 904	18.6	A.R.A."A"	18 621	1.6	DUDLEY	11 517	0.0
3	P.S.	75 591	16.3	P.S.	100 856	23.0	P.&R.	10 644	6.5	A.R.A."B"	52 410	9.0
4	P.R.R.	433 405	18.7	DUDLEY	176 284	34.0	A.S.C.E.	139 042	9.0	A.S.C.E.	188 021	9.2
5	P.&R.	8 900	32.6	A.S.C.E.	650 932	36.2	DUDLEY	4 404	11.4	P.S.	122 229	12.3
6	A.R.A."A".	11 165	33.1	P.&R.	8 900	62.8	P.S.	73 767	14.0	P.&R.	19 000	15.7
7	A.S.C.E.	654 572	36.6	N.Y.N.H.&H.	29 822	64.3	N.Y.N.H.&H.	20 566	21.4	A.R.A."A"	39 488	21.6
8	DUDLEY	179 647	50.6	A.R.A."A"	17 879	77.1	P.R.R.	2 546	55.0	N.Y.N.H.&H.	30 553	30.7
9										P.R.R.	1 107	52.3
	TOTAL =	1,474.494	MEAN: 30.1		1 587 402	29.0		289.155	10.0		477 095	12.0
						90-LB.						
1	A.R.A."A"	60,546	17.2	A.R.A."A"	92 891	19.0	SANTA FE	21 117	3.8	SANTA FE	148 224	4.3
2	G.N.	46 500	21.5	A.S.C.E.	911 106	46.4	G.N.	53 965	8.2	A.R.A."A"	305 264	8.9
3	D.L.&W	4 192	43 0	REROLLED	13 418	48.3	A.R.A."A"	183 345	10.1	C.S.	147 987	9.1
4	A.S.C.E.	885 635	61.3	C.S	115 020	61.6	D.L.&W.	48 327	16.3	D.L.&W.	65 959	21.9
5	C.S	113 486	67.4	A.R.A."B"	140 746	82.7	C.S.	114 112	16.3	A.R.A."B"	154 867	25.3
6	A.R.A."B"	121 465	92.0	G.N.	40 776	91.5	A.R.A."B"	148 747	17.8	A.S.C.E.	96 823	50.5
7							A.S.C.E.	60 034	72.6	G.N.	88 428	53.1
		1 231 824	61.0		1 313 957	51.0		629 947	19.1		1 007 552	20.0
						85-LB.						
1	M.P.	122,120	5.7	O.R.&N.	4 352	13.8	A.S.C.E.	324 379	10.0	M.P.	8 946	
2	P.R.R	609 279	17.5	P.R.R.	615 583	18.6	P.S.	41 515	14.0	A.S.C.E.	419 141	
3	P.S.	94 965	29.3	A.R.A."A"	3 916	20.0	A.R.A."A"	18 333	14.7	P.S.	62 684	
4	A.S.C.E.	2 676 902	35.4	M.P.	123 307	27.2	M.P.	5 946	21.9	A.R.A."A"	22 841	
5	C.B.&Q.	266 745	57.6	P.S.	121 860	32.0	C.B.&Q.	10 000	30.0	C.B.&Q.	10 000	
6	A.R.A."A"	1 964	112.0	A.S.C.E.	2 599 295	33.0				C.P.	45 955	
7				C.B.&Q	208 995	41.5						
8				C.P.	44 285	51.0						
		3 771 975	33.0		3 721 755	32.0		400 173	11.3		569 607	14.0
						80-LB.						
1	A.R.A."A"	7 508	0	A.R.A."A"	5 212	0.0	A.S.C.E.	362 473	27.3	N.Y.N.H.&H.	18 642	7.4
2	DUDLEY	275 495	16.5	C.S.	4 000	0.0				A.S.C.E.	426 317	43.9
3	A.S.C.E.	1 762 850	26.5	REROLLED	33 652	3.3						
4	CAMBRIA	3 708	45.8	DUDLEY	255 249	13.1						
5				A.S.C.E.	1 909 933	21.5						
6				CAMBRIA	6 141	34.1						
		2,049,561	25.1		2 214 187	20.0		362 473	27.3		449 559	42.0
						75-LB.						
1	M.P.	73 477	2.9	P.R.R.	1 566	0.0	C.S.	32 865	2.8	C.S.	28 099	1.7
2	P.R.R.	1 563	12.8	M.P.	75 570	3.4	LACKAWANNA	2 960	6.8	A.S.C.E.	60 506	8.4
3	B.&M.	37 063	13.2	A.S.C.E.	353 419	11.0	A.S.C.E.	61 510	12.8	B.&M.	11 135	24.1
4	A.S.C.E.	645 019	21.0	O.R.&N.	8 709	12.6						
5	C.S.	312 435	44.1	C.S.	312 487	55.0						
6				B.&M.	176 778	58.2						
		1,069,957	28.2		928,529	34.0		97 335	9.2		99 740	9.0
	Grand total for 1910: 9,600,000 tons; 34.0 failures per 10,000 tons; 1 failure per 812 rails or 1 failure per 2.3 miles of track.			Grand total for 1911: 9,800,000 tons; 31.0 failures per 10,000 tons; 1 failure per 891 rails or 1 failure per 2.5 miles of track.			Grand total for 1910: 1,800,000 tons; 17.0 failures per 10,000 tons; 1 failure per 1452 rails or 1 failure per 4.1 miles of track.			Grand total for 1911: 2,600,000 tons; 20.0 failures per 10,000 tons; 1 failure per 1234 rails or 1 failure per 3.5 miles of track.		

A.R.A. "A" - Am. Ry. Assn. Type "A".
A.R.A. "B" - " " " "B".
A.S.C.E. - Am. Soc. C.E.
B.&M. - Boston & Maine
CAMBRIA - Cambria Steel Co. - Special
C.B.&Q. - Chicago, Burl. & Quincy R.R.
C.P. - Canadian Pacific Ry.
C.S. - Common Standard - Harriman Lines
D.L.&W. - Del, Lack., & Western R.R.
DUDLEY - P.H. Dudley - N.Y.C. Lines
G.N. - Great Northern Ry.
LACKAWANNA - Lack. Steel Co. - Special
M.P. - Missouri Pacific Ry.
N.Y.N.H.&H. - New York, N.H. & H. Ry.
O.R.&N. - Oregon R.R. & Navigation Co.
P.&R. - Philadelphia & Reading R.R.
P.R.R. - Pennsylvania R.R. (Old)
P.S. - Pennsylvania System (New)
REROLLED - Rerolled rails.
SANTA FE - A.T. & S.F. Ry.

TABLE 3

Comparison of Failures of the Six Principal Sections of 100-Lb., 90-Lb. and 85-Lb. Rail of Bessemer and O. H. Steel for the Years 1910 & 1911.

[Compiled from Statistics of the American Railway Engineering Ass'n.]

BESSEMER STEEL													
YEAR	WT. PER YD.	TOTAL TONNAGE AND NUMBER OF FAILURES PER 10,000 TONS.											
		A·S·C·E·		A·R·A·"A"		A·R·A·"B"		P·R·R·		DUDLEY		P·S·	
1910	100	654,572	36.6	11,165	33.1	81 235	12.4	433,405	18.7	179,647	50.6	75,591	16.3
1911	100	650 932	36.2	17 879	77.1	137 904	18.6	464 825	16.9	176284	34.0	100 856	23.0
1910	90	885 635	61.3	60 546	17.2	121 465	92.0						
1911	90	911 106	46.4	92 891	19.0	140 746	82.7						
1910	85	2 676 902	35.4	1 964	112.0			609 279	17.5			94 965	29.3
1911	85	2 599 295	33.0	3916	20.0			615,583	18.6			121 860	32.0
		7,398,442	43.0	188 361	31.3	381 350	79.6	2,123,092	18.1	355,931	43.7	393,272	26.5
Grand total: 10,800,000 tons; 38.3 failures per 10,000 tons.													

OPEN HEARTH STEEL													
YEAR	WT. PER YD.	TOTAL TONNAGE AND NUMBER OF FAILURES PER 10,000 TONS.											
		A·S·C·E·		A·R·A·"A"		A·R·A·"B"		P·R·R·		DUDLEY		P·S·	
1910	100	139,042	9.0	18,621	1.6	19 565	1.0	2,546	55.0	4 404	11.4	73 767	14.0
1911	100	188 021	9.2	39 488	21.6	52 410	9.0	1 107	52.3	11 517	0	122 229	12.3
1910	90	60 034	72.6	183 345	10.1	148 747	17.8						
1911	90	96 823	50.5	305 264	8.9	154 867	25.3						
1910	85	324 379	10.0	18 333	14.7							41 515	14.0
1911	85	419 141	6.3	22 841	16.5							62 684	12.7
		1,227,440	14.8	587,892	14.0	375,589	19.1	3 653	54.0	15,921	3.2	300,195	13.1
Grand total: 2,510,000 tons; 14.6 failures per 10,000 tons.													

Note. For names of sections see bottom of Table 2.

P·R·R· Section is now superseded by the P·S· Section as the standard of the Penna. Lines.

A·F·C·

TABLE 4

Comparison of the Physical Properties of Five of the Principal Sections of 100-Lb. Rail.

PROPERTIES	SECTION				
	A·S·C·E·	A·R·A·"A"	DUDLEY	A·R·A·"B"	P·S·
Height, overall	5 3/4"	6"	6"	5 41/64"	5 11/16"
Width of flange (base)	5 3/4"	5 1/2"	5 1/2"	5 9/64"	5"
" " head	2 3/4"	2 3/4	3"	2 9/16"	2 1/2"
Thickness of head	1 45/64	1 9/16"	1 5/8"	1 45/64"	1 52/64"
" " web	9/16"	9/16"	19/32"	9/16"	9/16"
" " flange (base)	31/32"	1 1/16"	31/32"	1 5/64"	1 3/32"
Radius of tread	12"	14"	14"	12"	10"
" " top corner of head	5/16"	3/8"	5/16"	3/8"	7/16"
Area of head	4.12	3.64	4.06	3.95	4.09
" " web	2.06	2.29	2.32	1.89	1.85
" " base	3.62	3.91	3.46	4.01	4.03
Per cent. of metal in head	42.0	36.9	41.2	40.2	41.0
" " " " " web	21.0	23.4	23.6	19.2	18.6
" " " " " base	37.0	39.7	35.2	40.6	40.4
Ratio periphery of head to area	1.68	1.80	2.32	1.64	1.59
" " " web " "	3.20	3.21	3.20	3.60	3.58
" " " base " "	3.10	3.29	3.04	2.49	2.43
" total periphery to total area	2.52	2.92	2.80	2.37	2.30
Moment of Inertia	44.4	48.9	49.7	41.3	41.9
Section Modulus	15.0	15.0	15.8	13.7	14.7
Distance from base to neutral axis	2 5/64"	2 3/4"	2 109/128"	2 5/8"	2 81/128"
Section Modulus of head		15.0		13.7	13.7
" " " base		17.8		15.7	15.9
Date adopted	1893	1908	1892	1908	1907
By what railroads used	Very general	Several	N·Y·C·Lines	Several	Penna. Lines

A·S·C·E· - American Society of Civil Engineers
A·R·A·"A" - American Railway Association
A·R·A·"B" - " " "
DUDLEY - Dr. P·H·Dudley
P·S· - Pennsylvania System

TABLE 5.

* Comparative Amounts of Open-Hearth and Bessemer Steel Rails Manufactured from 1900 to 1913.

Year	Open-Hearth (Tons)	Bessemer (Tons)	Total (Tons)
1900	1,333	2,384,349	2,385,682
1901	2,093	2,872,546	2,874,639
1902	6,029	2,941,904	2,947,933
1903	45,054	2,947,423	2,992,477
1904	145,833	2,138,828	2,284,711
1905	183,262	3,192,667	3,375,929
1906			3,977,887
1907	252,704	2,839,963	3,633,654
1908			1,921,015
1909	1,256,674	1,767,171	3,023,845
1910	1,715,899	1,918,130	3,634,029
1911	1,676,923	1,145,867	2,822,790
1912	2,105,144	1,099,926	3,327,915

* From statistics of the American Iron and Steel Institute.

TABLE 6.

* Total Production of Steel Rails from 1886 to 1913.

Year	Total Tons Produced	Year	Total Tons Produced
1886	1,579,000	1900	2,385,682
1887	2,119,000	1901	2,874,639
1888	1,390,000	1902	2,947,933
1889	1,513,000	1903	2,992,477
1890	1,871,000	1904	2,284,711
1891	1,298,000	1905	3,375,929
1892	1,541,000	1906	3,977,887
1893	1,130,000	1907	3,633,654
1894	1,017,000	1908	1,921,015
1895	1,300,000	1909	3,023,845
1896	1,117,000	1910	3,634,029
1897	1,645,000	1911	2,822,790
1898	1,977,000	1912	3,327,915
1899	2,271,000		

* From statistics of the American Iron and Steel Institute.

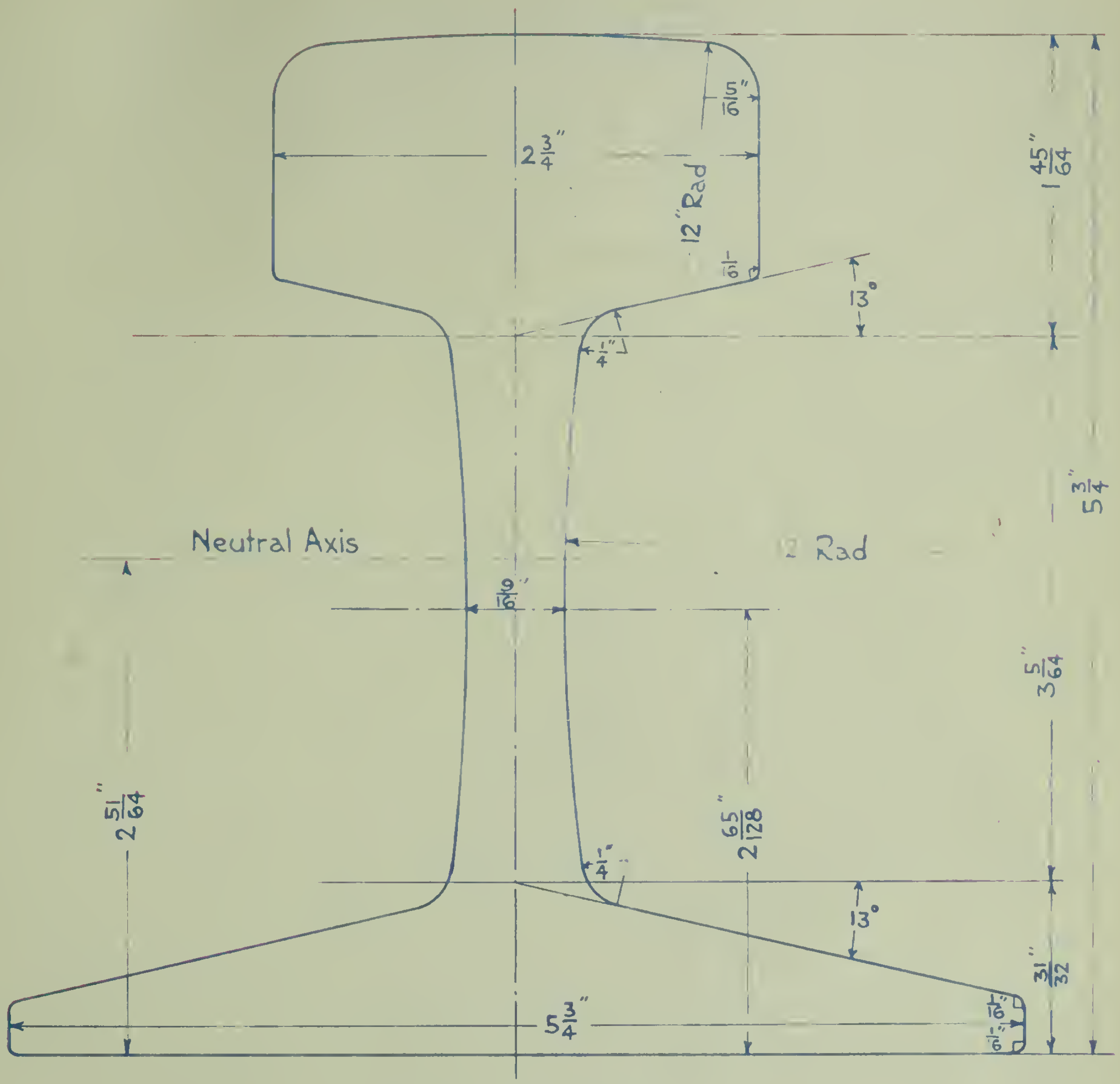
TABLE 7.

Speeds of the Fastest American Trains.

	Railroad	Train	From		To	Time	Distance Miles	Av. Speed Mi. per Hr.
1.	Baltimore & Ohio	Royal Limited	New York	-	Washington	5 hr. 0 m.	225	45.0
2.	C. B. & Q.	Fast Mail	Chicago	-	Council Bluffs	11 " 0 "	493	44.8
3.	C. M. & St. P.	Columbian	Chicago	-	St. Paul	12 " 15 "	410	32.5
4.	D. L. & W.	Lackawanna Ltd.	Buffalo	-	New York	9 " 42 "	410	42.7
5.	Pennsylvania R.R.	#69	Phila.	-	Washington	2 " 40 "	135	50.5
6.	" "	Manhattan Ltd.	Pittsburg	-	Altoona	2 " 52 "	114	39.6
7.	L. S. & M. S.	Fast Mail	Chicago	-	Buffalo	11 " 55 "	525	44.4
8.	N. Y. C. & H. R.	Empire State Express	Buffalo	-	New York	9 " 10 "	439	47.8
9.	Lehigh Valley	Black Diamond Express	Buffalo	-	New York	11 " 30 "	448	38.9
10.	N. Y. N. H. & H.	Bay State Ltd.	New York	-	Boston	5 " 0 "	232	46.8
11.	"	Bankers' Express	New Haven	-	New York	1 " 34 "	73.2	48.8
12.	Pennsylvania R.R.	Broadway Ltd.	New York	-	Chicago	18 " 0 "	909	50.5
13.	N.Y.C. & H.R.	20th Century Limited	New York	-	Chicago	18 " 0 "	960	53.4
14.	Illinois Central	Panama Ltd.	Chicago	-	New Orleans	24 " 0 "	930	38.7

Note: Time given is from terminal to terminal. The average speed does not take into account the time lost in stops.

Average of 7 of the fastest trains (Nos. 1, 4, 5, 7, 8, 10, and 11) = 45.5 miles per hour for an average run of 293 miles.



Scale: Full Size.

Area of head	4.12 sq. in.	42.0%	Ratio periphery of head to area		1.68
" " web	2.06 "	21.0%	" " " web " "		3.20
" " base	3.62 "	37.0%	" " " base " "		3.10
Total	9.80	100.0%	" total periphery to area		2.52

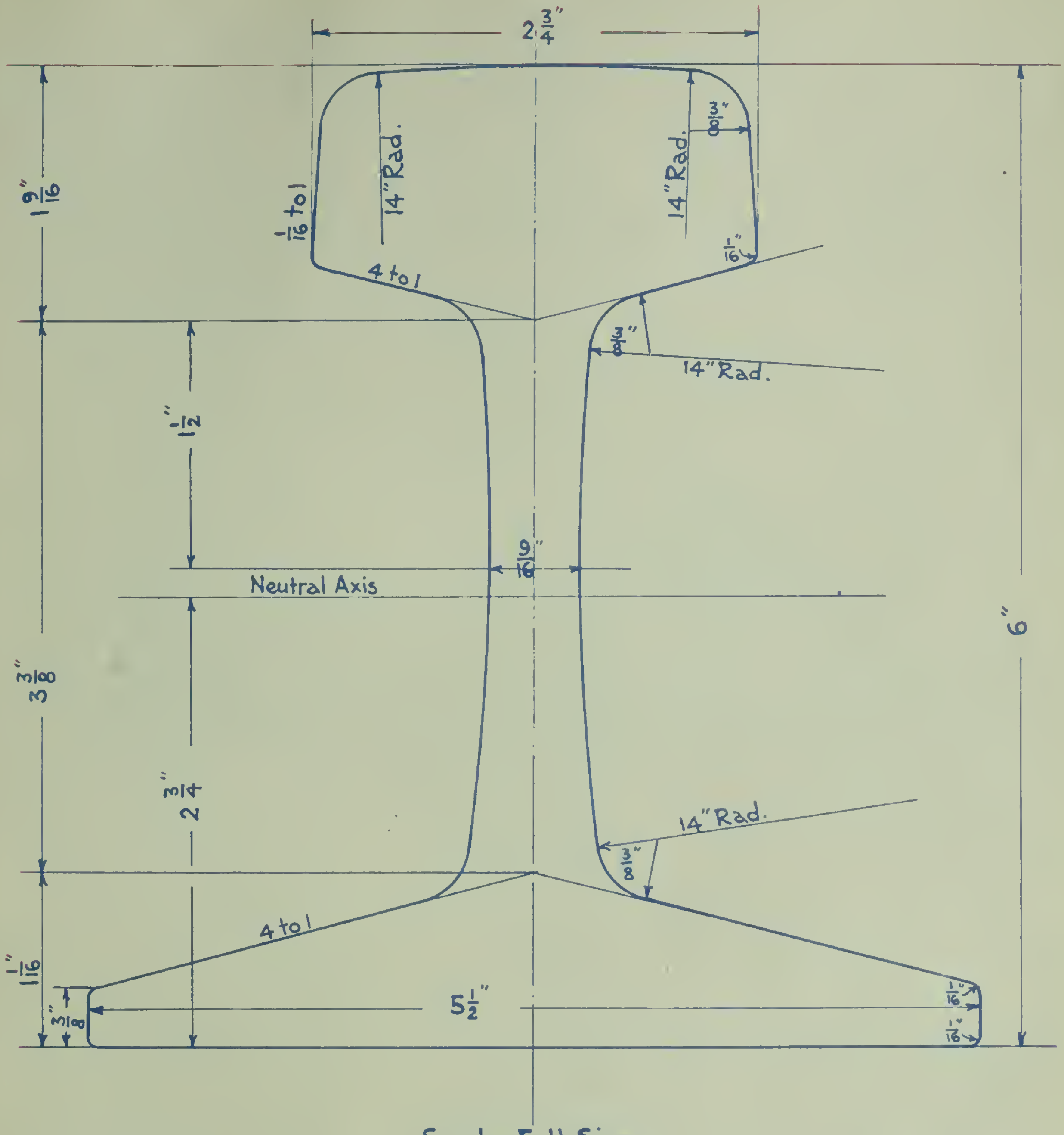
Moment of Inertia 44.4   Section Modulus 15.0

Section Modulus of head

" " " base

FIG. 1, 100-LB. A.S.C.E. SECTION. (Adopted 1893.)

A.F.C.



Scale: Full Size.

Area of head	3.64 sq. in.	36.9 %	Ratio periphery of head to area	1.80
" " web	2.29 "	23.4 %	" " " web " "	3.21
" " base	3.91 "	39.7 %	" " " base " "	3.29
Total	9.84 "	100.0 %	" total periphery " "	2.92

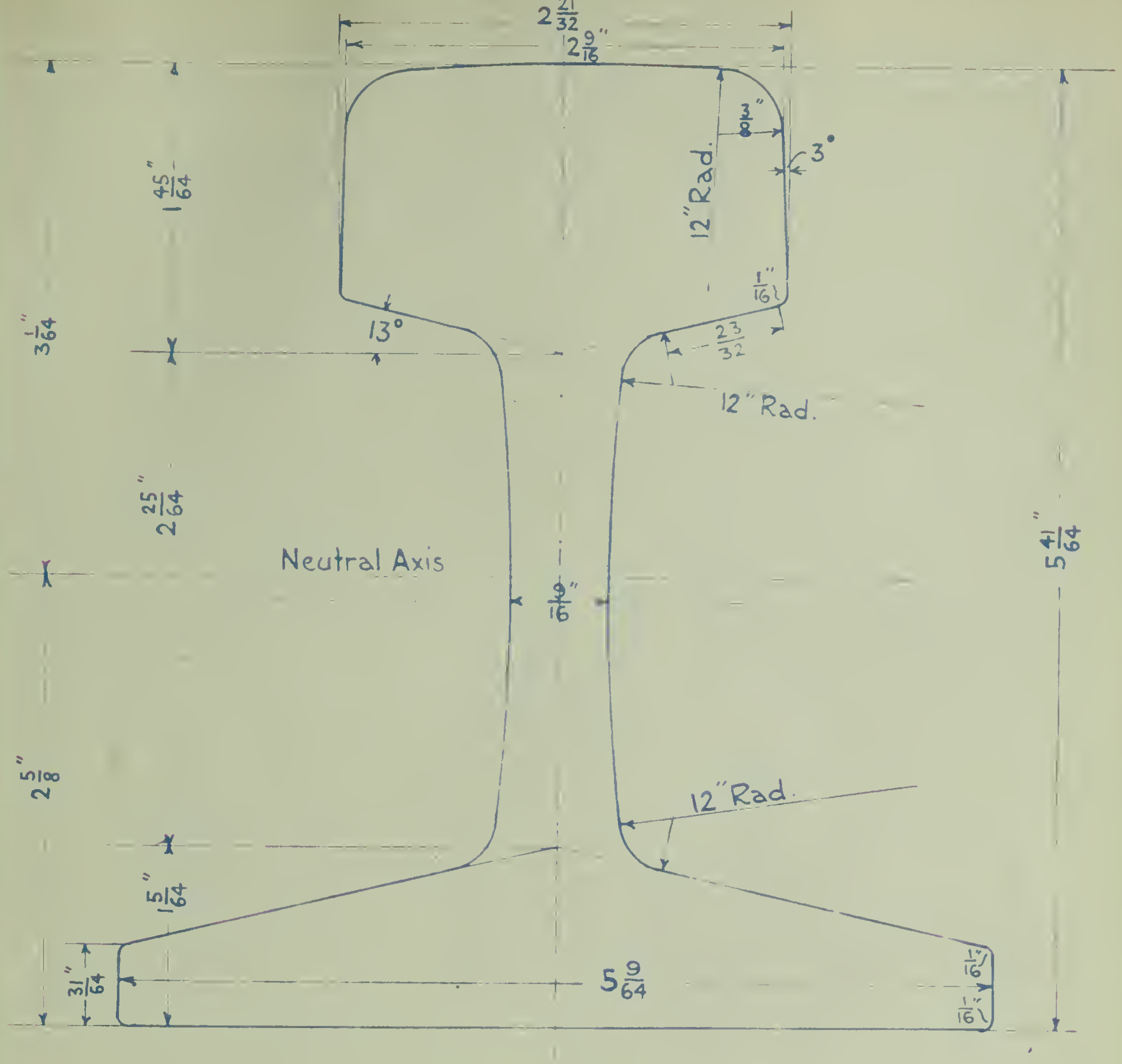
Moment of Inertia 48.94. Section Modulus 15.0

Section Modulus of head 15.04

" " " base 17.78

FIG. 2, 100-LB. A.R.A. "A". SECTION. (Adopted 1908.)

A.F.C.



Scale Full Size.

Area of head	3.95	sq. in.	40.2 %	Ratio Periphery Head to Area	1.64
" " web	1.89	"	19.2 %	" " Web " "	3.60
" " base	4.01	"	40.6 %	" " Base " "	2.49
Total	9.85	"	100.0 %	" total periphery " "	2.37

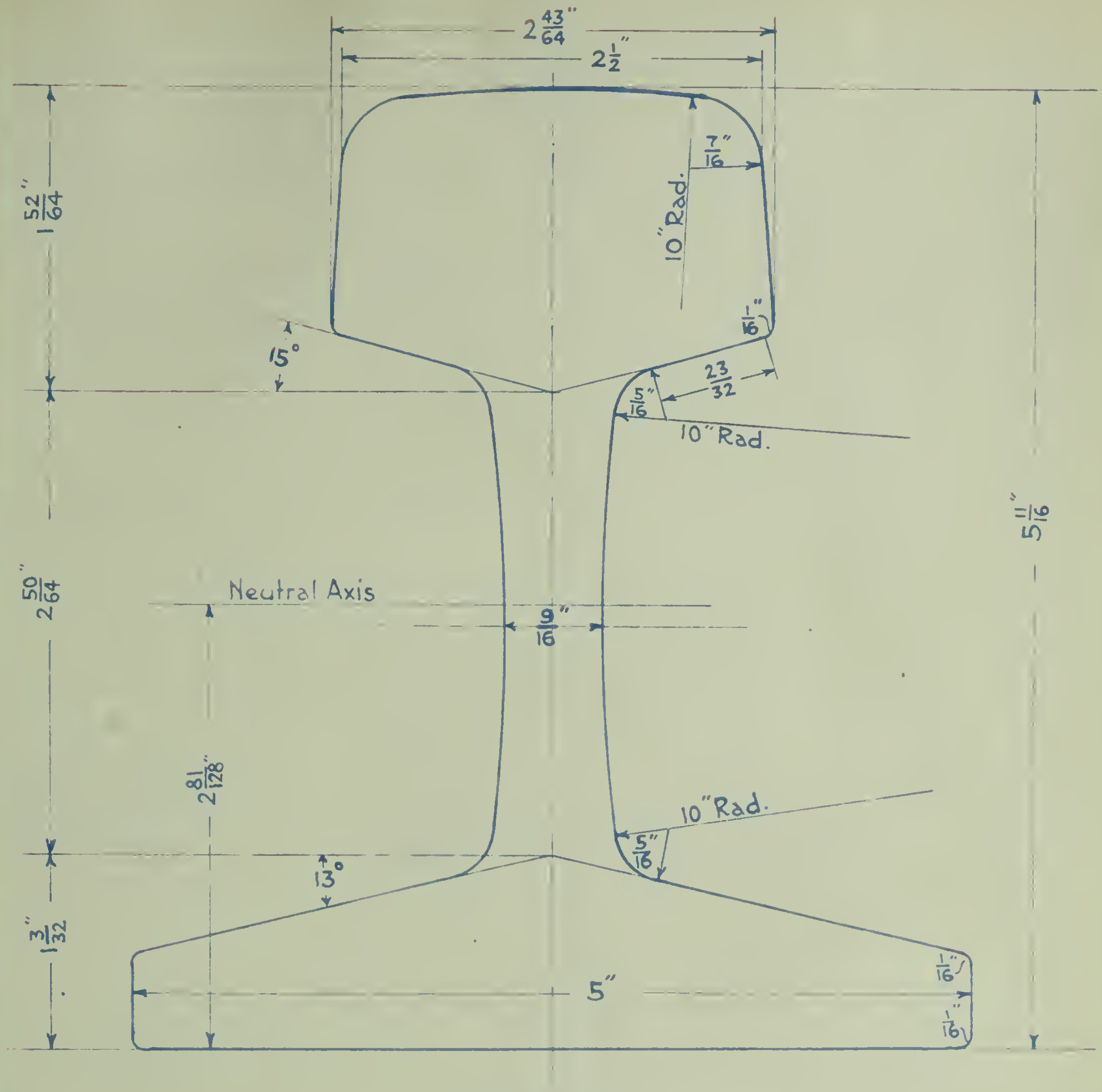
Moment of Inertia 41.3 Section Modulus 13.7

Section Modulus of head 13.70

" " " base 15.74

A.F.C.

FIG 3, 100-LB. A.R.A. "B" SECTION (Adopted 1908.)



Scale: Full Size

Area of head	4.09 sq. in.	41.0 %	Ratio periphery of head to area	1.59
" " web	1.85 "	18.6 %	" " " web " "	3.58
" " base	4.03 "	40.4 %	" " " base " "	2.43
Total	9.97	100.0 %	" total periphery to total "	2.30

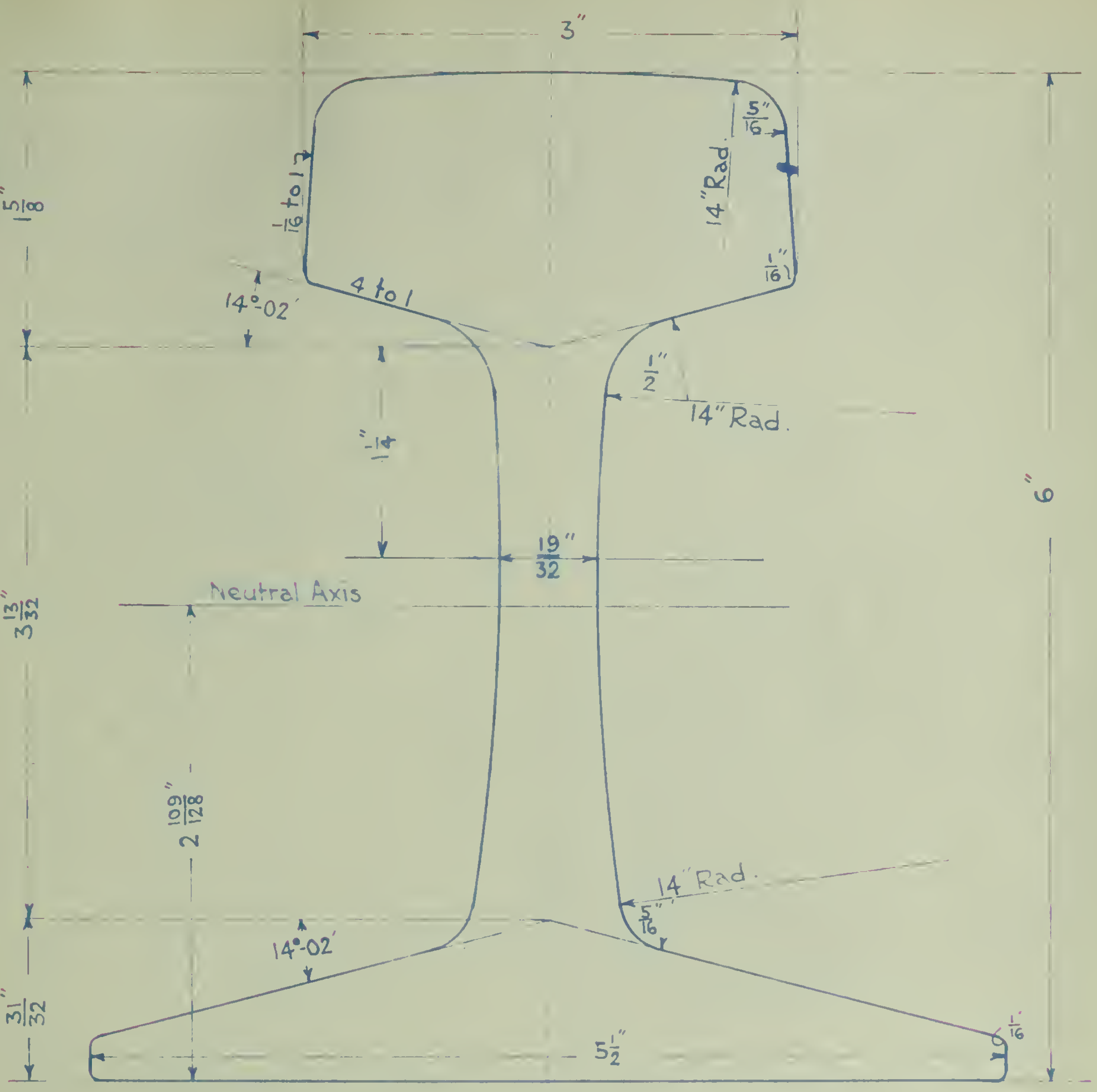
Moment of Inertia 41.9 Section Modulus 14.7

Section Modulus of head 13.7

" " " base 15.9

FIG. 4. 100-LB. PENNSYLVANIA R.R SYSTEM (P.S) SECTION. (Adopted 1907.)

A.F.C



Scale: Full Size.

Area of head	4.06 sq in.	41.2%
" " web	2.32 "	23.6%
" " base	3.46 "	35.2%
	9.84	100 0%

Ratio periphery of head to area	2.32
" " web " "	3.20
" " base " "	3.04
" total periphery to total "	2.80

Moment of Inertia 49.8

Section Modulus 15.8

Section Modulus of head

" " " base

FIG. 5, 100-LB. DUDLEY SECTION (Adopted 1892.)

A. F. C.

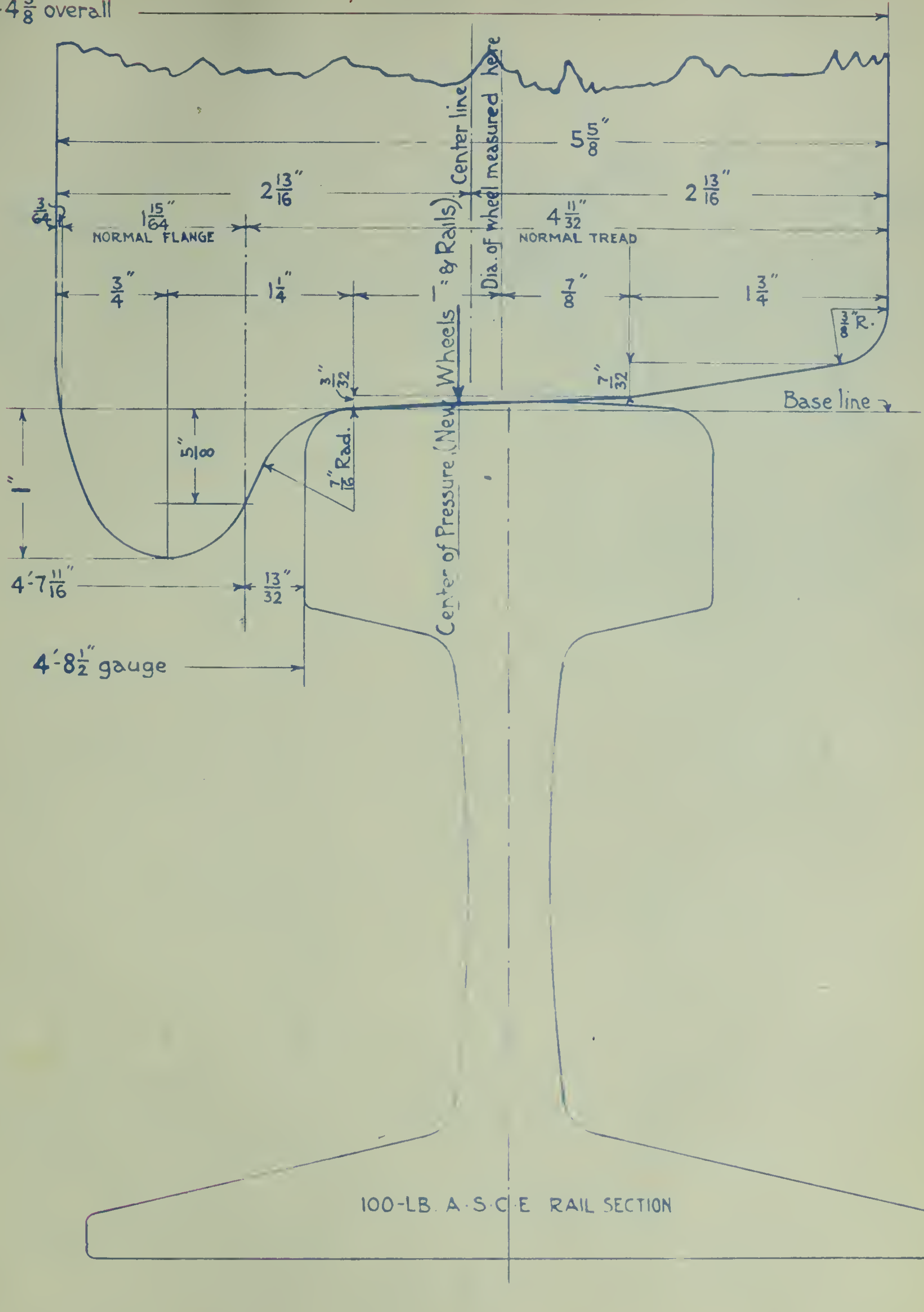


FIG. 6, SECTION SHOWING M.C.B. STANDARD CAR-WHEEL ON RAIL.

A.F.C.

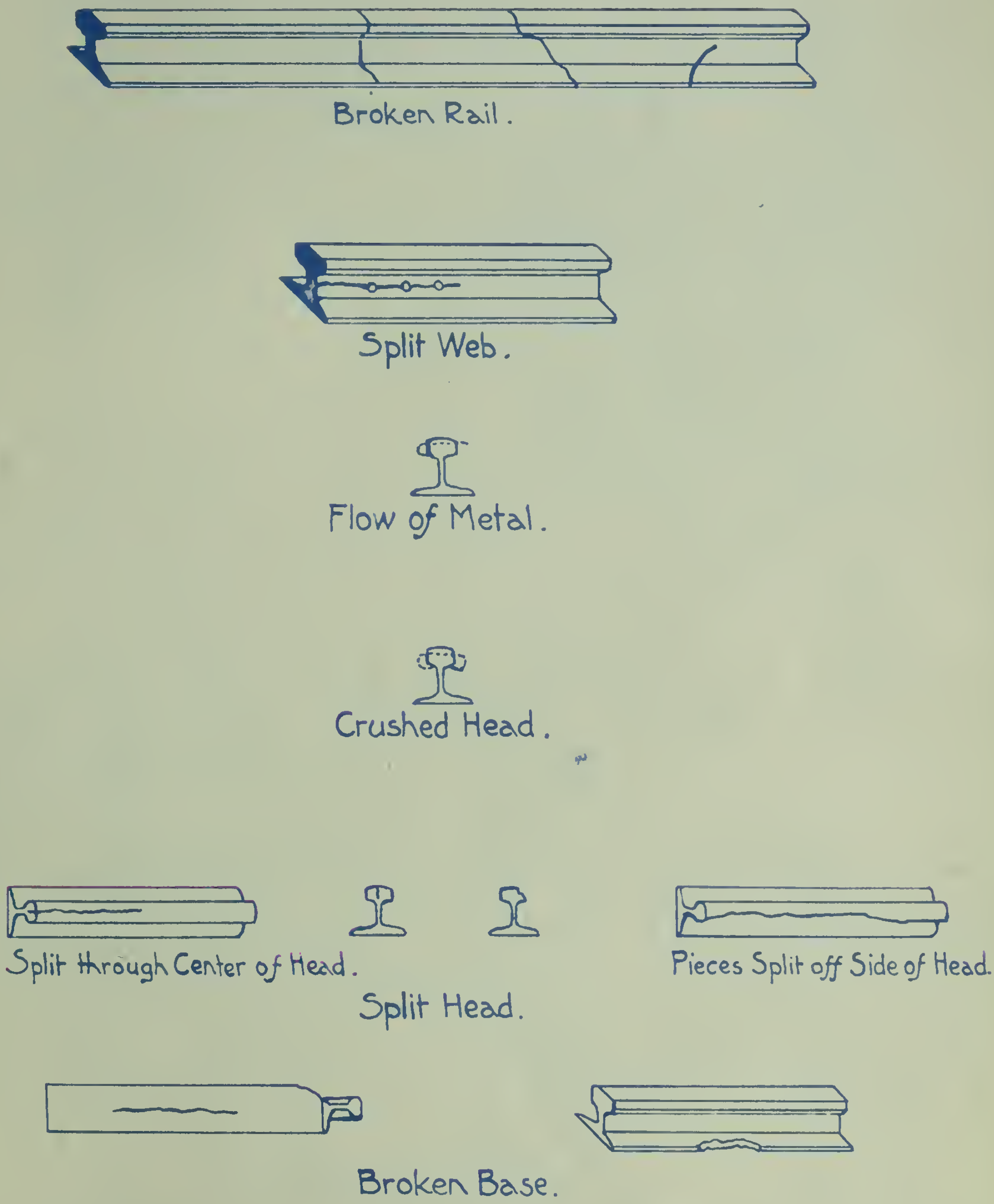
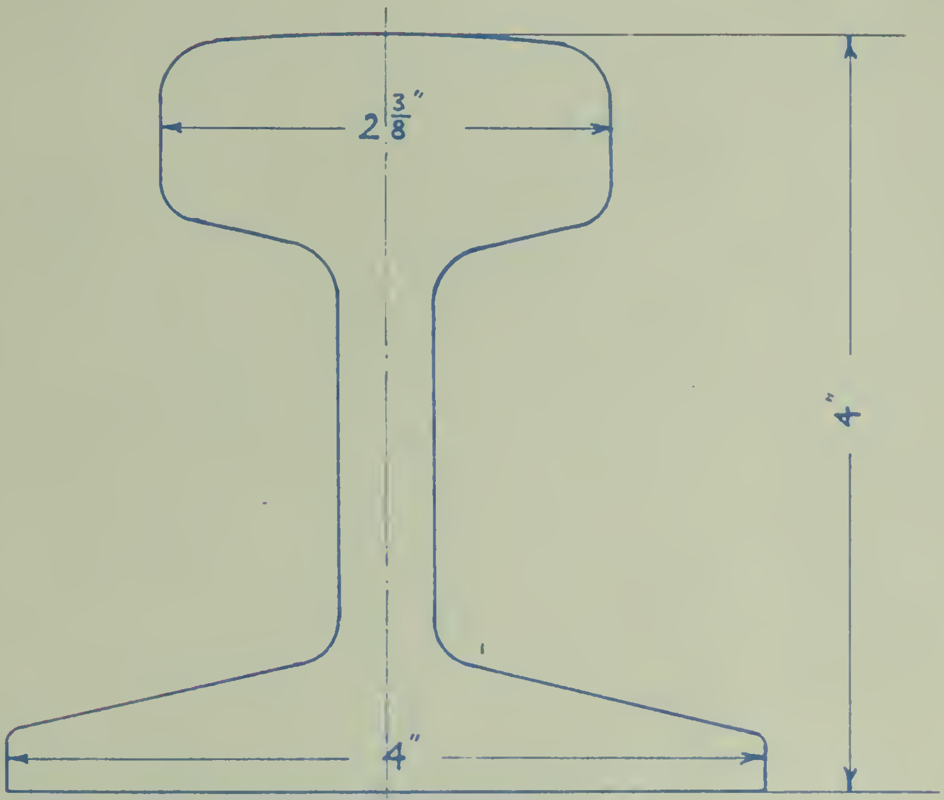


FIG. 7, ILLUSTRATING TYPICAL RAIL FAILURES.

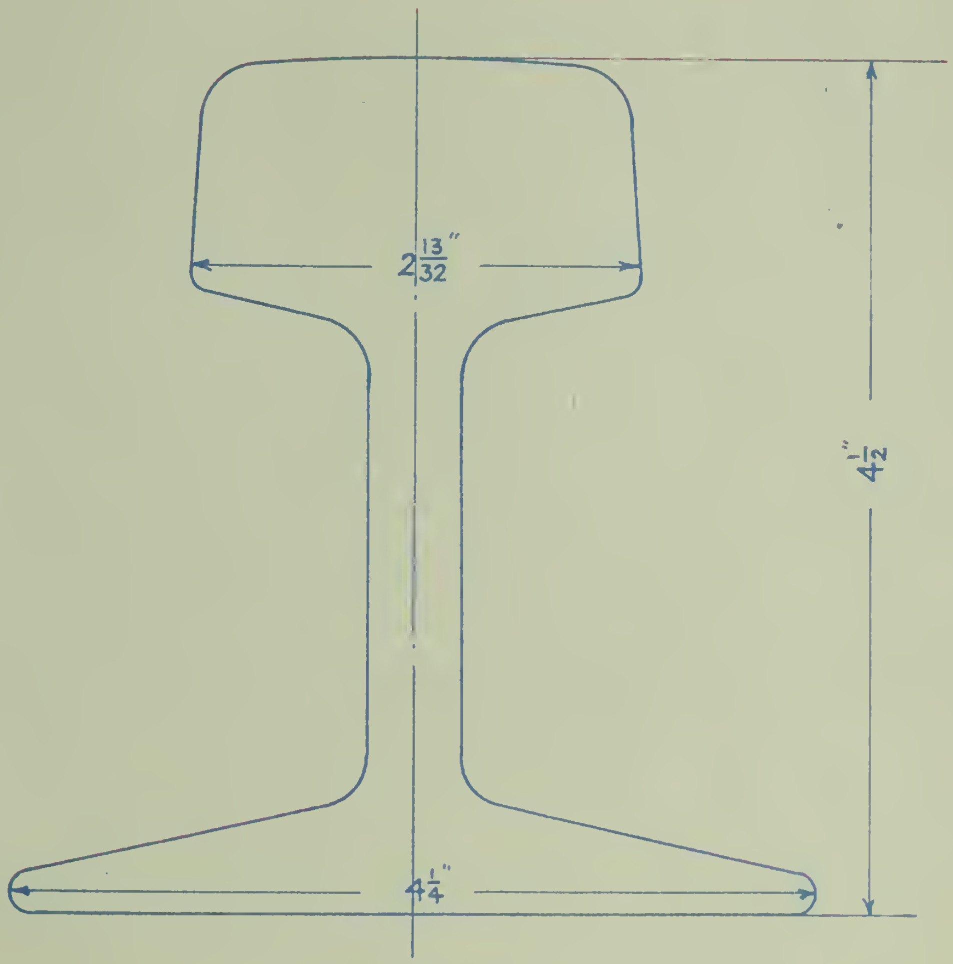
A.F.C.



Scale: Full Size.

FIG. 8. ASHBEL WELCH $57\frac{1}{2}$-LB. SECTION, CAMDEN & AMBOY R.R., 1866.
This is one of the earliest sections of steel rail rolled in the United States.

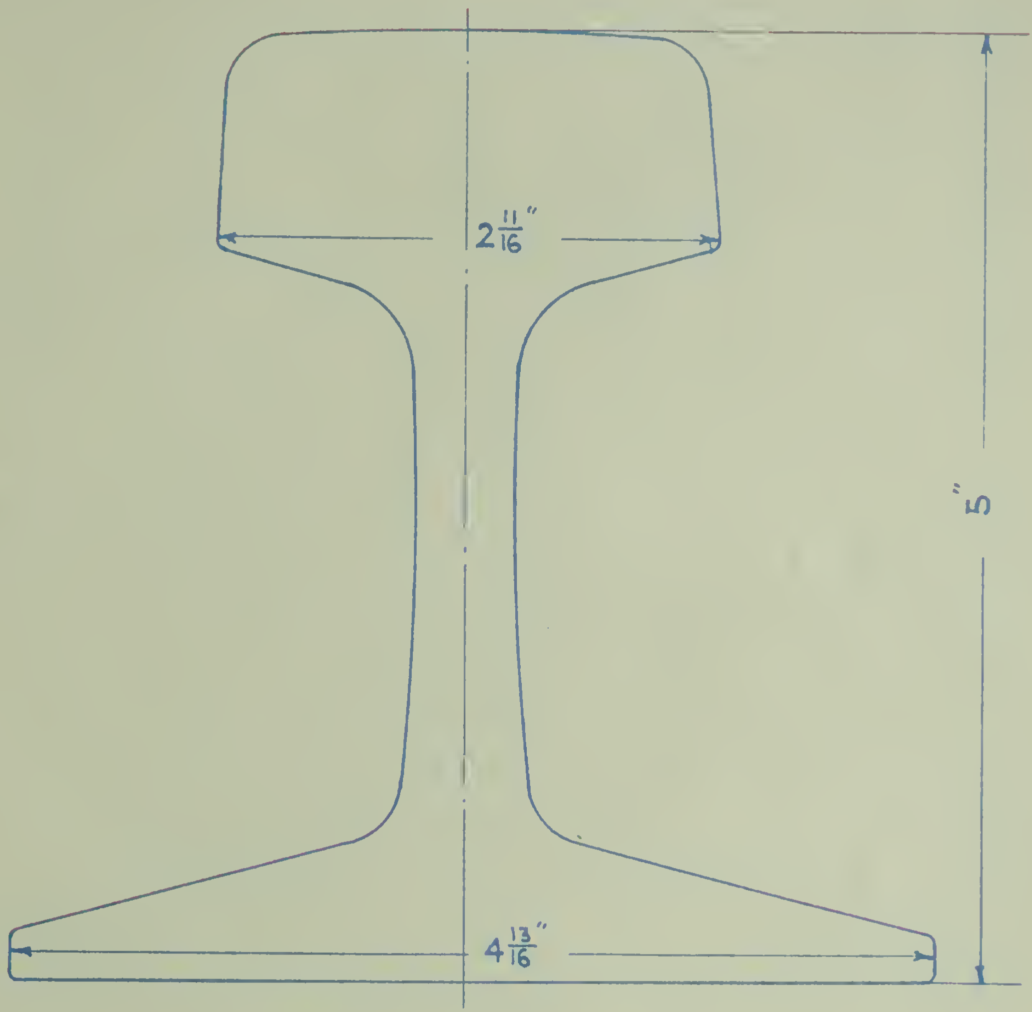
A.F.C.



Scale: Full Size.

FIG. 9. N·Y·C· & H·R·R·R· STANDARD 65-LB·RAIL, 1881.
Superseded by 80-lb. rail, beginning in 1884.

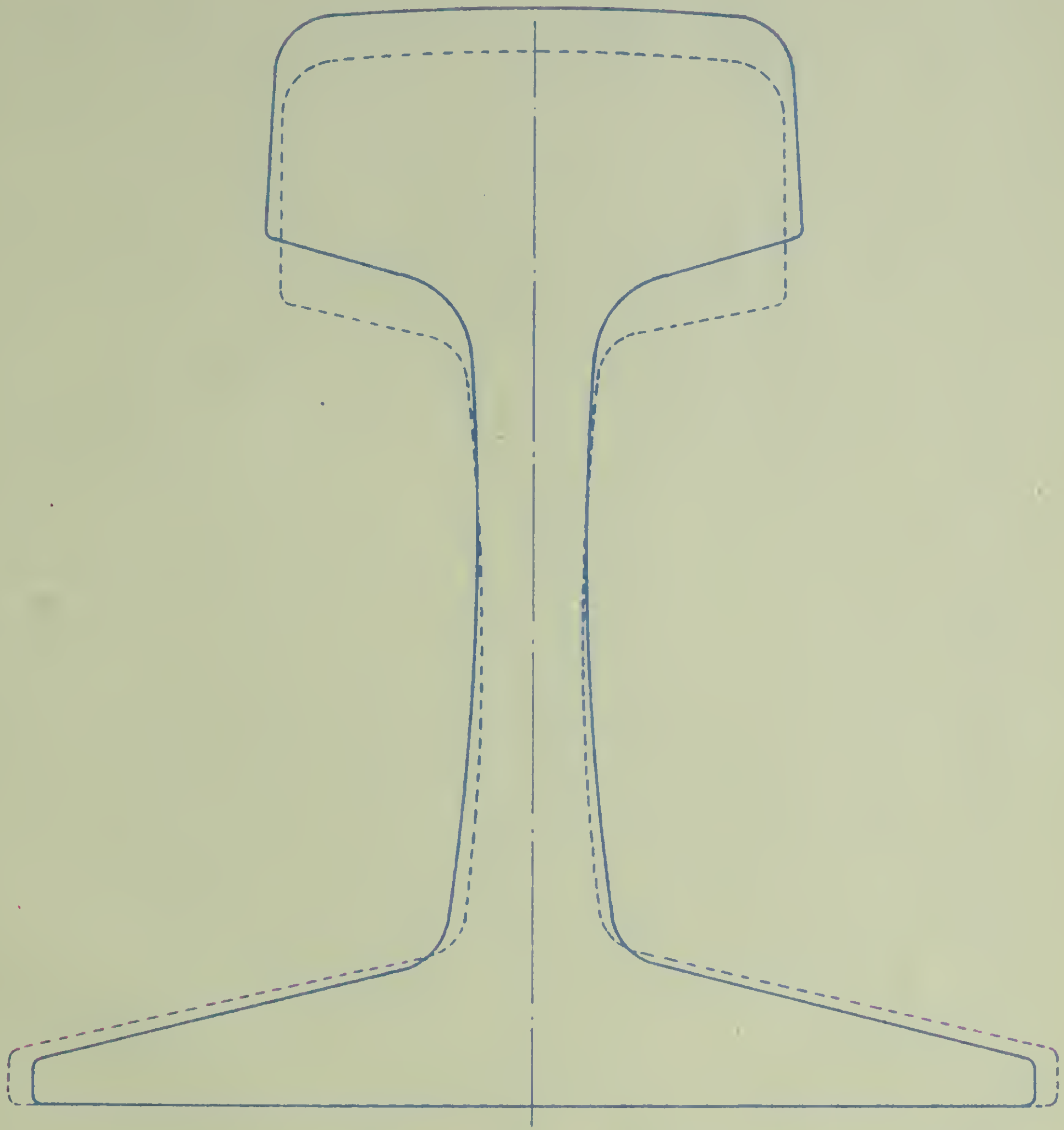
A·F·C·



Scale: Full Size.

FIG. 10. N·Y·C· & H·R·R·R· STANDARD 80-LB· RAIL, 1884.
The *first* 80-lb rail used on American railroads.

A·F·C·

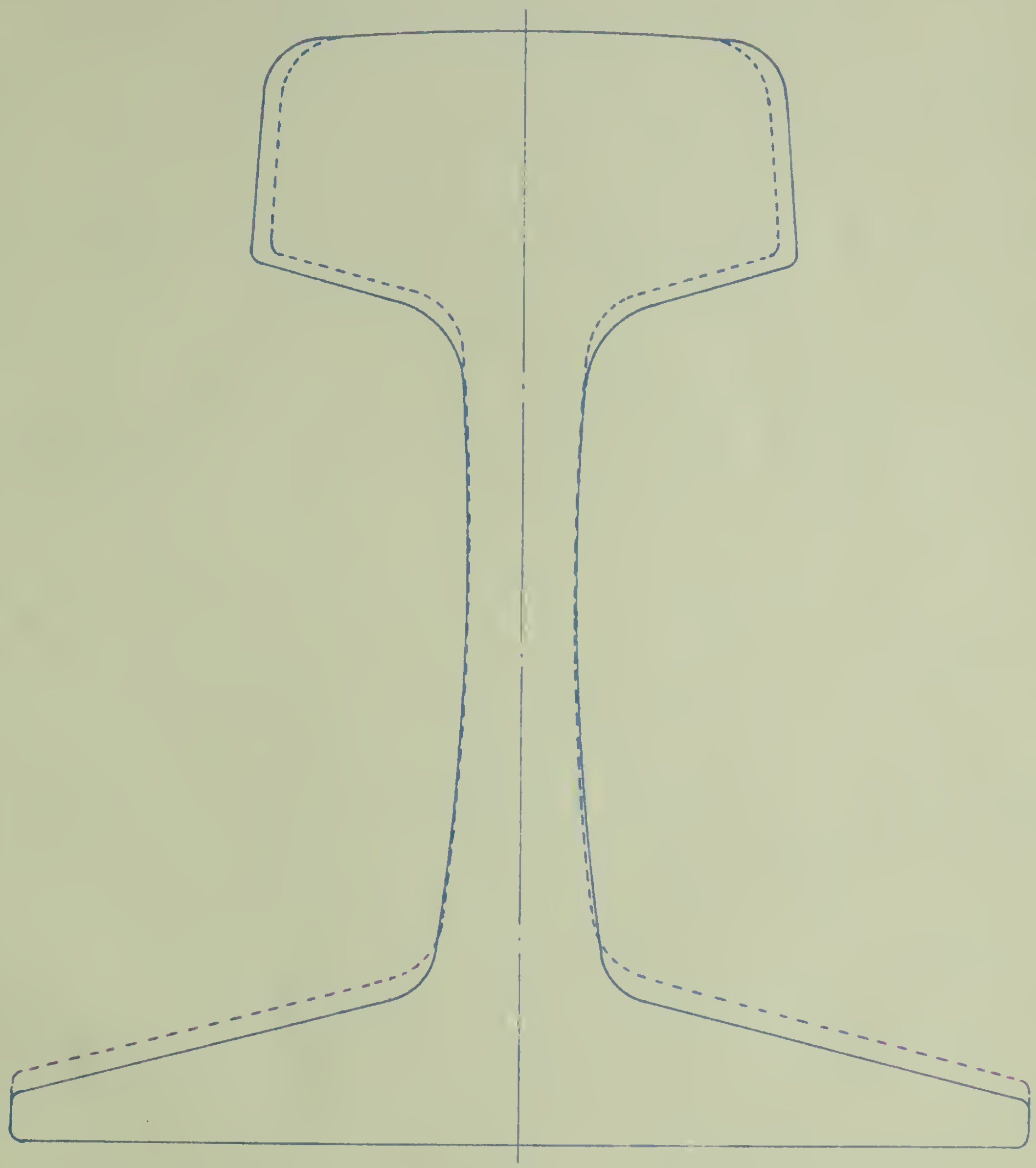


Scale: Full Size.

———— Full lines show Dudley Section.
- - - - - - Dotted lines show A·S·C·E· Section.

FIG·11. COMPARISON OF DUDLEY AND A·S·C·E· 100-LB. RAILS.

A·F·C



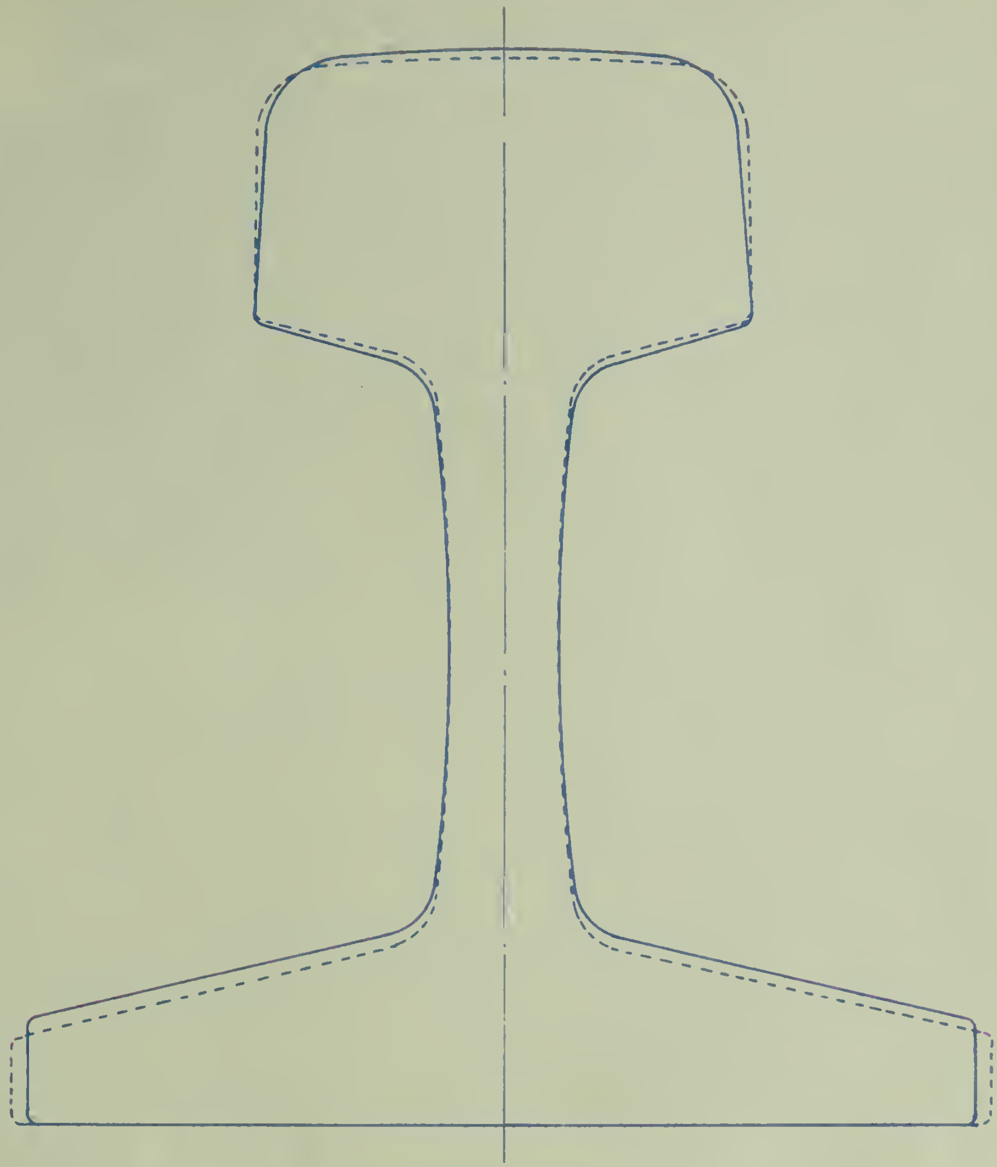
Scale: Full Size.

———————— Full lines show Dudley Section.

- - - - - - - - Dotted lines show A·R·A·"A". Section.

FIG. 12. COMPARISON OF DUDLEY AND A·R·A· "A" 100-LB. RAILS.

A·F·C·



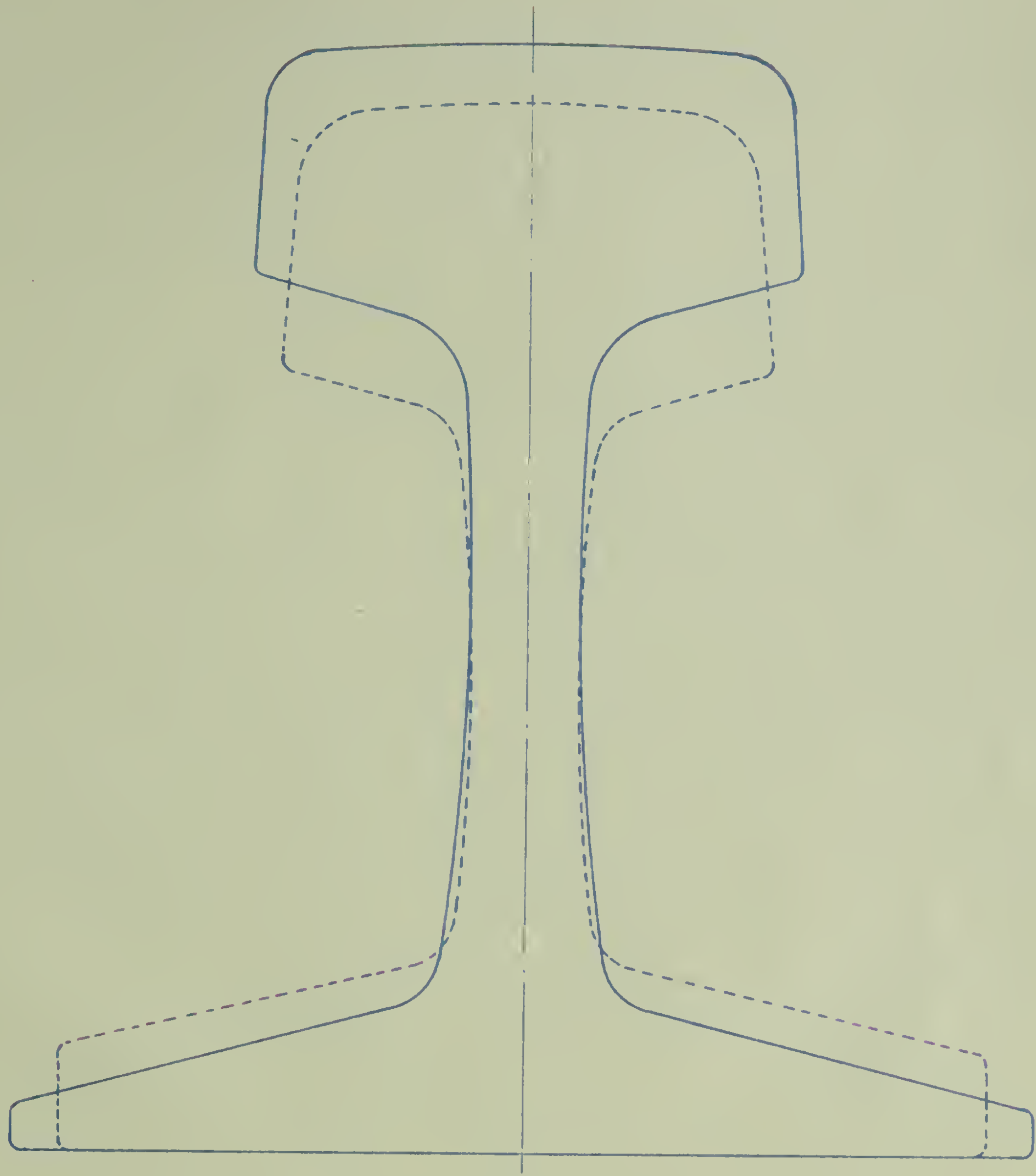
Scale: Full Size.

———————— Full lines show P·S· Section.

- - - - - - - - -Dotted lines show A·R·A· "B" Section.

FIG·13. COMPARISON OF P·S· AND A·R·A· "B" 100-LB. RAILS.

A·F·C·



Scale: Full Size.

——————— Full lines show Dudley Section.

- - - - - - - - - Dotted lines show P.S. Section.

FIG. 14. COMPARISON OF DUDLEY AND P.S. 100-LB. RAILS.

A.F.C.